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THESIS

MODELING OF HELICOPTER PILOT MISPERCEPTION DURING OVERLAND NAVIGATION

by

Bradley T. Cowden

March 2012

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This thesis provides a framework to model human belief and misperception in helicopter overland navigation. Helicopter overland navigation is a challenging mission area because it is a complex cognitive task, and failing to recognize when the aircraft is off-course can lead to operational failures and mishaps. A human-in-the-loop experiment to investigate pilot misperception during simulated overland navigation by analyzing actual navigation trajectory, pilots' perceived location, and corresponding confidence levels was designed. Fifteen military officers with prior overland navigation experience completed four simulated low-level navigation routes, two which entailed autonavigation. Analysis shows that there is not a negative correlation between perceived and actual location of the aircraft, inferring that confidence is not a good indicator of performance. There is however some evidence that there is a negative correlation between perceived location and intended route of flight, suggesting that there is a bias towards that intended flight route. If aviation personnel can proactively identify the circumstances in which usual misperception occur in navigation, they may reduce mission failure and mishap rate. Fleet squadrons and instructional commands can benefit from this study to improve operations that require low level flight while also improving crew resource management.

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MODELING OF HELICOPTER PILOT MISPERCEPTION DURING OVERLAND NAVIGATION

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ABSTRACT

This thesis provides a framework to model human belief and misperception in helicopter overland navigation. Helicopter overland navigation is a challenging mission area because it is a complex cognitive task, and failing to recognize when the aircraft is off-course can lead to operational failures and mishaps. A human-in-the-loop experiment to investigate pilot misperception during simulated overland navigation by analyzing actual navigation trajectory, pilots' perceived location, and corresponding confidence levels was designed. Fifteen military officers with prior overland navigation experience completed four simulated low-level navigation routes, two which entailed autonavigation. Analysis shows that there is not a negative correlation between perceived and actual location of the aircraft, inferring that confidence is not a good indicator of performance. There is however some evidence that there is a negative correlation between perceived location and intended route of flight, suggesting that there is a bias towards that intended flight route. If aviation personnel can proactively identify the circumstances in which usual misperception occur in navigation, they may reduce mission failure and mishap rate. Fleet squadrons and instructional commands can benefit from this study to improve operations that require low level flight while also improving crew resource management.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AGL	Above Ground Level
CP	Check Point
FEST	Flight and Eye Scan Visualization Tool
FOV	Field of View
GPS	Global Positioning System
MOVES	Modeling, Virtual Environments and Simulation
MSL	Mean Sea Level
OTW	Out-The-Window
PAC	Pilot At The Controls
PNAC	Pilot Not At The Controls
RMS	Root-Mean Square
SDT	Signal Detection Theory
TERF	Terrain Flight
TLM	Topographical Land Map
WP	Waypoint

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EXECUTIVE SUMMARY

Objective:

This thesis provides a framework to model human belief and misperception in helicopter overland navigation. Helicopter overland navigation is a challenging mission area because it is a complex cognitive task, and failing to recognize when the aircraft is off-course can lead to operational failures and mishaps.

Methods:

Systematic biased perception during an overland navigation was observed in Sullivan *et al.* (2010). In the current study, we design a human-in-the-loop experiment to investigate pilot misperception during simulated overland navigation by analyzing actual navigation trajectory, pilots' perceived location, and corresponding confidence levels. Fifteen military officers with prior overland navigation experience completed four simulated low-level navigation routes, two which entailed autonavigation.

Results:

Data was collected regarding the amount of time the participants spend in the "dangerous" off track and high confidence area of perception, the correlation between perception and confidence, and the relation of confidence and error versus time. Data was categorized into four quadrants based off perception error and corresponding confidence levels; eg, "On-track" with "High" or "Low" confidence and "Off-track" with "High" or "Low" confidence. Subjects were "On-track" and had a corresponding "High" confidence 58.37% of the time, but the second most frequent state was the dangerous quadrant, "Off-track" yet still confident that they are "On-track." Of the time pilots were "Off-track" (34.65%), they had wrong perception 77.86% of the time. This observation was more explicit in autonavigation scenarios at 81.55%. Hypothesis testing was conducted to determine if there is a negative correlation between the distance between actual and perceived location of the aircraft versus confidence, if there is a negative correlation between the distance between the perceived location of the aircraft and intended route of flight, and if confidence and perception error increases with time of

flight. Analysis shows that there is not a negative correlation between perceived and actual location of the aircraft, inferring that confidence is not a good indicator of performance. There is however some evidence that there is a negative correlation between perceived location and intended route of flight, suggesting that there is a bias towards that intended flight route. Lastly, confidence tends to decrease while perception error increases the longer the pilot navigates.

Implication:

If aviation personnel can proactively identify the circumstances in which usual misperception occur in navigation, they may reduce mission failure and mishap rate. Fleet squadrons and instructional commands can benefit from this study, especially for use in search and rescue, anti-surface warfare, combat search and rescue, and naval special warfare operations because of the low-level navigation flight profiles required. This study can also improve crew resource management inside the helicopter cockpit. Helicopter crews are heavily reliant on each member of the crew, and additional complacency can occur when one of the members is confident that they are on course.

KEYWORDS: Training, Simulation, Human Factors, Aviation, Helicopter, Navigation, Confidence, Overconfidence, Perception, Misperception, Bayes

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I. INTRODUCTION

A. RESEARCH OBJECTIVE(S)

The goal of this research is to understand pilot's perception and confidence during overland navigation, and why these may lead to visual misperception. Mishaps and mission failure have been linked to improper navigation, and these problems increase when the pilot is unaware of their miscalculations. Although it is recognized that misperception during navigation is dangerous, we are unaware of studies that use quantitative analysis to link the specific factors of why pilot misperception is prevalent. We seek to address this critical question in order to develop training and tools to improve the problem.

In this study, participants were placed in a high cognitive workload simulated environment based on real-word scenarios and their performance was evaluated. We evaluate performance by measuring the distance between the participant's perceived location, compared to their actual location, and their corresponding confidence level. Results from the study are expected to be used to improve pilot training, crew coordination, and aircraft or cockpit design and technologies.

B. BACKGROUND

1. Helicopter overland navigation

Helicopter overland navigation is a challenging and complex cognitive task. Helicopter overland navigation is comprised of a number of sub-skills that require continuous visual cue perception and decision making. The "Flight Training Instruction, Instrument and Navigation Advanced Phase, TH-57" states that the "Pilot Not At the Controls (PNAC) is primarily responsible for accurate navigation. He must remain oriented at all times, monitor cockpit instruments, and perform assigned cockpit duties as briefed. During an aircraft or system emergency, he executes the emergency procedures as briefed by the pilot"(CNATRA P-458). The navigational task can be done by visual navigation, dead reckoning, or electronic navigation using Global Positioning System (GPS), Doppler Radar, or some other system. Visual navigation is performed by

comparing terrain features on a map to what is seen out the window of the aircraft. Dead reckoning involves taking a known position and by using direction and timing. Advances in GPS technology have decreased the use of visual navigation and dead reckoning, yet can still only be used as a form of backup navigation in all fleet aircraft and a critical skill if ever required to. The PNAC may use all three forms of navigation, separately or in combination, in order to accurately navigate through low-level terrain. On top of this heavy navigational workload, the PNAC's most important role is to assist the Pilot At the Controls (PAC) in obstacle avoidance. Because of the complex cognitive task placed on the nonflying aviator, it is easy to deviate from course. Straying off course is not an issue if the aviator is aware of being off course. However, often the aviator is unaware of being off course.

2. Misperception and Overconfidence

Misperception can lead to both mission failure by the aircraft not reaching its intended destination on time, and also mishaps due to the pilot flying into obstacles in the terrain. The Navy Safety Center has adopted James Reason's Swiss cheese model for understanding the underlying process that results in mishaps (Reason, 2000). The Swiss cheese model relates a system to a stack of slices of Swiss cheese. Each slice of cheese is a layer of the system, and the holes are analogous to opportunities for the system to fail. Mishaps occur only when the holes line up allowing failures to pass through without being stopped by another system. This research focuses on the slice that relates to pilot judgment. There are two particular recent mishaps that expose the importance of exploring information on the subject. The first mishap involved an MH-60S with 17 individuals on board. In this mishap, they were flying in a new area when unexpected bad weather arrived. They tried to deviate from the intended course to a nearby landing field. The crew relied heavily on visual navigation because they did not have the divert airfield in their cockpit navigational computer. This lack of information, along with the low cloud layer, caused the crew to misperceive their location, and ultimately lead to a crash landing in the snow covered West Virginia mountains. The second mishap involved a senior pilot and aircrew flying a MH-60S under daytime clear atmospheric conditions. The senior pilot had a vast knowledge of the area, but decided to not follow

course rules back to their home station. They hit power lines and crashed the helicopter. This mishap was due to overconfidence in the pilot on where they perceived they were flying. The pilot's confidence contributed to the complacency of the co-pilot and aircrew. Luckily, in both of these mishaps no one was killed, but it did highlight the fact that misperception can have drastic consequences.

3. Related research

Table 1 presents a matrix derived from signal detection theory (SDT) showing the four different awareness states of a navigating pilot (Sullivan, 2010). The most concerning area is marked "Dangerous," where the crew believes that they are on course when they are not. This thesis focused on this type of misperception because it lends itself to mishaps and mission failures.

Assessing Navigation Performance		Confidence	
		Low	High
Correctness	Low	Struggling. No accurate fix, aware that aircraft is off track	**Dangerous**. Lost and doesn't realize it. Positively misidentified correlating features.
	High	On course and lucky. Accurate fix, but not confident in navigation solution.	Skilled performer. On track and certain.

Table 1. Matrix for Assessing Navigational Skills (After Sullivan, 2010). We see that the most dangerous combination is low correctness and high confidence, and the pilots do not recognize the loss of situational awareness.

Sullivan et al. (2010) collected navigation and eye scan pattern data from 12 military officers who underwent an overland navigation simulation. This experiment had pilots navigate through 12 waypoints in a simulation terrain model of Twentynine Palms, CA. Regression analysis confirmed previous results that flight performance measures such as RMS (root-mean square) error were not predicted by the expertise level of pilots (Bellenkes, Wickens & Kramer 1997). However, Sullivan et al. (2010) found that gaze parameters and scan management skills were predicted by the expertise level. Most

relevant to this study, analysis through Flight and Eye Scan visualization Tool (FEST, Figure1) showed that some pilots had biased perception. As shown in Figure 1, subject five missed a waypoint and started to track north of the intended route. Instead of using available visual cues on the flight simulation screen or out-the-window (OTW) to realize that he was off course, he perceived that he was still on course. This pattern suggests the pilot was using some biased visual cueing in which he overweighed OTW cues that fit into his perception that he was on course, and disregarded OTW cues that did not fit with his hypothesis.

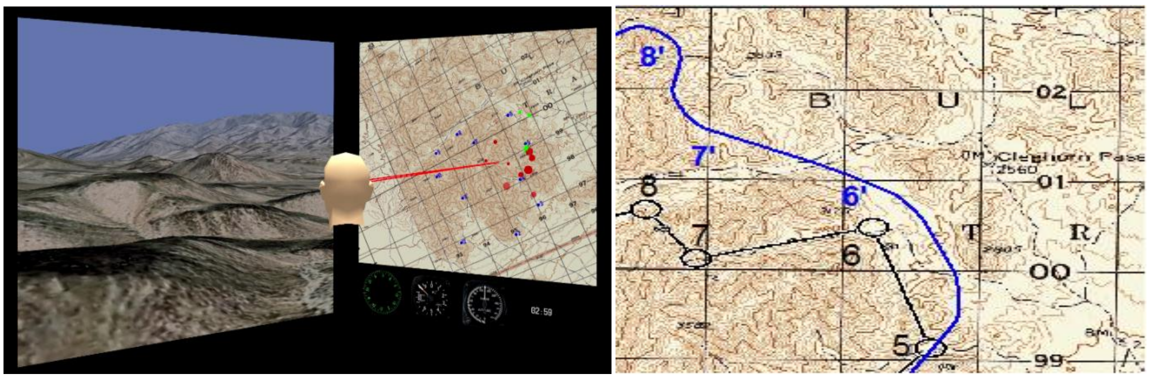

Figure 1. Left: Flight and Eye Scan visualization Tool (FEST) and Right: Subject five's actual flight trajectory (blue) and planned route (black) (right) (Sullivan et al. 2011 and Yang et al. 2011)

Yang used data gathered from Sullivan's experiment and classified pilot misperception into three types (Yang, Kennedy, Sullivan & Day, 2011). Type one is confusion between inference and evidence. This type is especially seen when the pilots have a high belief that they are on-track. Type two is when pilots incorrectly assume mutually exclusive evidences based on a highly-likely visual cue for multiple locations. The third type is when pilots discount cues that do not correspond to their hypothesis. This misperception type can be attributed to inattentional blindness (Simons & Chabris, 1999). Table 2 summarizes the three misperception types compared to Bayesian perception.

Perception type	Posterior probability
Bayesian agent (A)	$p(H\|d) = \frac{p(d\|H) \cdot p(H)}{p(d\|H) \cdot p(H) + p(d\|{\sim}H) \cdot p({\sim}H)}$
Misperception Type 1 (B1)	$p(H\|d) = p(d\|H)$ when $p(d\|H) \approx 1$
Misperception Type 2 (B2)	$p(H\|d) = \frac{p(d\|H) \cdot p(H)}{p(d\|H) \cdot p(H) + (1 - p(d\|H)) \cdot p({\sim}H)}$ $\mathrm{p(H\|d)} = \frac{\mathrm{p(d\|H) \cdot p(H)}}{\mathrm{p(d\|H) \cdot p(H) + (1\text{-}p(d\|H)) \cdot p({\sim}H)}}$ when $p(d\|H) \approx 1$
Misperception Type 3 (B3)	$p(H\|d) = p(H)$ when $p(d\|H) \approx 0$

Table 2. Visual misperception modeling using a Bayesian framework (From Yang et al., 2011); where d = terrain features that the pilot sees, and H = pilots current position

Bayesian updating centers on the fact that subjective beliefs should be updated with the addition of some evidence. Orbán claimed in his paper, “Bayesian Learning of Visual Chunks by Human Observers,” that humans act and learn as logical Bayesian agents even if they are unaware of this fact. Humans are able to update conditional probabilities to make correct maximizing or minimizing choices in complex environments (Orbán, Fiser, Aslin & Lengyel, 2008). For this type of Bayesian cognitive modeling, human errors are not considered. These errors, to include misperception, are very important in determining why aviators get off track. Knowing that a pilot is acting as Bayesian agent is not as useful as knowing why the pilot is not acting as a Bayesian agent. When pilots are not acting as a Bayesian agent there is greater chance of them getting off-course.

Inattentional blindness, or perceptual blindness, occurs when a person is overwhelmed with inputs causing them to miss a stimulus that is in plain sight. Simons and Chabris (1999) demonstrated this phenomenon by showing a video of two groups of people passing a basketball to participants. The participants were supposed to count the number of passes made in the video. During this video a person dressed as a gorilla walks through the scene. Fifty percent of the subjects tested did not notice the gorilla in the video. Sullivan (2010)’s data showed the inattentional blindness. The high cognitive workload experienced in helicopter low level navigation results in pilots focusing on certain inputs, for example gauges map, and terrain. However, they miss other inputs that an outsider could consider obvious. After the fact, it is easy to show pilots that they

missed substantial terrain features, just as it was easy to show participants that they missed the gorilla in the video. OTW gaze data showed the pilot “looked” at the terrain which is a cue for realizing that they are off-track. However, they did not “perceive” the cue they were looking at. During pilot training, students are instructed to refrain from fixating on one input and to keep their scan moving, yet this inattentional blindness is still observed.

Another theory on why pilot misperception occurs is overestimation of personal ability or overconfidence. Overconfidence leads pilots to perceive that they are on course even after they have drifted off course. After drifting off course, pilots will try to match their outside surrounding to the map, and not the converse. This overconfidence can be explained by Stone’s research of self-efficacy (Stone, 1994). In this experiment, he placed subjects in complex cognitive tasks and observed their behavior, performance, and perceptions. He found that the subjects were biased towards overestimates of personal ability; that is, they perceived their performance to be better than it actually was. This finding seems counterintuitive, because one would believe that they would be less confident when they are engaged in high workload environment. There can be two reasons for this overconfidence applied to navigation. The first is that the aviator is so task overloaded that they rely too heavily on their navigation abilities and training. Even if the pilot believes that they are getting behind on their navigation, they still believe that they are heading in the right direction because of previous good decisions and they do not have adequate time to get their precise location. The second reason for overconfidence is due to a lack of knowledge of the current situation. If a pilot has limited experience operating in a certain environment, they can be unaware of the dangers associated with it. An aviator who has never flown in the mountainous desert environment may apply incorrect navigational techniques assuming it will yield the same results.

C. RESEARCH QUESTIONS

My thesis models the different types of visual misperception and validates these classifications by making comparisons between what pilots see OTW and their alleged location on the map to the actual flight trajectory and location through human-in-the-loop experiments. The thesis focused on three areas: (1) Investigate correlation between

pilot's perception and confidence. (2) Provide misperception modeling in a Bayesian framework. (3) Given what we learn about pilot misconception, what training, operational or acquisition strategies should we recommend to the Navy to increase combat efficiency and decrease risks?

D. OUTLINE OF THESIS

Methods: This section covers the reason for experimental design and experimental hypotheses. This section also described the dependent and independent variables used and how they were collected. Experimental setup and procedures also fall under this section.

Analysis and Results: This section includes how experimental data was filtered, grouped, and/or correlated. The outputs of this analysis are presented.

Model: The model section includes model design, implementation, and output.

Conclusions and Recommendations: This section highlights and summarizes results from analysis and the model. This section also provides recommendations based off findings and contributions of the study. Future work suggestions are then presented.

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II. SIMULATOR-BASED HUMAN-IN-THE-LOOP EXPERIMENTS

A. EXPERIMENTAL HYPOTHESES

This section provides the reasoning for the experimental setup used to test initial hypotheses. The goal of the experiment was to place a participant with navigation experience in a situation where only visual terrain cues were available for navigating. Four hypotheses were constructed that focused on participants' perceived and actual location and self-assessed Figure of Merit, or confidence, during the visual navigation tasks. These four hypotheses will be analyzed in the following chapters.

The first null hypothesis is there no correlation between distance from actual helicopter position during pause points and the participant's perceived location and the participant's confidence of their perceived location. This hypothesis is based on the idea that one's confidence is not related to their navigation performance, or that one's confidence may even increase with greater navigation error. The alternative hypothesis was that there is a negative correlation between confidence and perception error. This hypothesis states that if a participant perceived themselves to be "lost," they would be able to recognize that fact and therefore have a corresponding low confidence level. This hypothesis test can also be related to unrecognized special disorientation. Unrecognized disorientation is considered the most dangerous of the three types of disorientation, and is when pilots are unable to correctly perceive what is happening in their surroundings. Failing to reject the null hypothesis for this case could be a causal factor for pilots getting off-track, along with the associated mishaps and mission failures.

The second null hypothesis tested is no correlation between the pilot's confidence and the distance between their perceived location and the intended route of flight. This hypothesis claims that when a pilot believes that they are off the intended route of flight, there would not be a corresponding low confidence level. The alternate hypothesis is that there is a negative correlation between confidence and distance between perceived and actual course. The reasoning behind this alternative hypothesis was because if a pilot was maintaining an accurate track and course, they would be close to the intended route.

Once a pilot believed that they have strayed off course, they would be more likely to be guessing at their current position. Failing to reject the null could show that pilots have a biased confidence belief even when they are not tracking on course.

The longer a participant navigates through an intended route, the greater the distance between the perceived location and the actual helicopter position was the third null hypothesis tested. The reasoning behind this null hypothesis was because it would be assumed that the longer a pilot navigates through a scenario the more likely they would deviate from their intended course. The causal factors for this could be because the participant has more time to stray off course, fatigue, or leg heading or timing was forgotten or not as fresh in the mind compared to earlier in the navigation route. The alternative hypothesis was that there not an increase in distance between perceived and actual location the longer into the participant navigates. Rejecting the null hypothesis would state that pilot misperception is not reliant on where on the route the aircraft is located.

The final hypothesis that was tested was that confidence decreased the further into the navigation route, or confidence is a function of time. The null hypothesis assumes that the confidence level of participant would reduce because of some causal factors. These factors could be because the pilot had more time to realize that they were off course, fatigue, or overtasked. The alternative to the null is that confidence does not decrease the longer the participant was flying. Results regarding this hypothesis would give insights into how pilots generate their confidence levels over a period of time.

B. EXPERIMENTAL METHOD

1. Task Definition

Low level navigation, or "terrain flight" (TERF), is defined as flight below 200 feet above ground level (AGL) (CNATRA P-458). This environment is challenging because the low flight level reduces the amount of terrain that the pilot can see, and requires intense emphasis on flight parameters. We focus on the navigation aspect of terrain flight; our simulated aircraft is held at constant altitude and does not experience emergencies – two critical dimensions of real-world TERF navigation. "Proficient

navigation during low-level flight requires training and practice. Identifying [check points] (CPs) is the critical task, since this requires the navigator to be proficient in map reading, terrain interpretation, and correlation of terrain features with map symbols. He must be able to visualize from the map how the terrain along the flight path should look. He must also be able to look at the terrain, identify his location, and locate it on the map" (CNATRA P-458).

Low-level VFR Navigation requires efficient visual scanning. Visual scanning is the ability to recognize and reference key terrain features in a given field of view. These key terrain features will allow the navigator to recognize waypoints and intermediate check points along the route. Pilots must also "be prepared for the terrain to look differently than as planned and adjust as necessary" (CNATRA P-458).

2. Navigation Route Design

The route environment and waypoint selection plays a large role in the outcome of this study. The route needed to be in a location that did not favor any particular pilot's previous Fleet experience and covered an area that had challenging terrain so that there was great possibility of misperceiving the surroundings. Finally, it needed to be an area adequately mapped in FALCONVIEW to use in our analysis. The mountainous area of Twentynine Palms was selected for this experiment for several reasons. The first being that the area includes some landmarks, and there are multitudes of executable routes. Secondly, most of the participants of the study have not operated in this area. Finally, we consider the high altitude desert terrain to be comparable to the current operating environments in Iraq and Afghanistan.

After choosing the operating area, routes were selected to support hypothesis testing. To collect sufficient data, four routes were generated, along with a practice route. The participant had to navigate through the route using a joystick which controlled heading (roll) only; participants had no control over pitch, yaw, power, or airspeed. The pilots did not have to control attitude, airspeed, rotor speed or ball, therefore greatly simplifying the navigational task. For the last two routes, a scripted "autopilot" guided the participant along a set course without their control.

The autonavigation routes were added to normalize the experiment in the following manner: If all of the participants were able to control the helicopter through the routes, each pilot would see different terrain features because the probability of two independent pilots flying the same course is practically zero. Controlling the route with the autopilot allowed the experiment proctor to pause the route at the exact same points, so that each participant sees the same terrain. More than this, it ensures that each pilot is presented the terrain identically – that they approach it from the same azimuth and roll angle.

With the number and types of routes chosen, the waypoints comprising the route were selected. The routes needed to be fair, yet challenging enough for the pilots to get off-course. We subjectively created routes that were appropriate for a late-first tour aviator’s level of experience.

The practice route was designed to get the participant familiar with the control of the helicopter, feel comfortable using the confidence program, establish a scan pattern, and gain familiarity with the interfaces. The practice route was a short, four-waypoint route. This route was based off prominent landmarks, yet still required the pilot to make large heading changes.

Figure 2 shows the intended path of the practice route. The waypoints are the circles labeled one through four. Adjacent to each leg is a navigational totem, colloquially referred to as a “doghouse,” oriented in the intended direction of flight. The doghouse contains four pieces of navigational data. On the top of the doghouse is the number of the next waypoint on the intended route. Below the waypoint entry is the intended magnetic heading followed by the distance of the leg in nautical miles (nm). The last number on the doghouse is time it takes to fly the given leg traveling at 65 kts. “Doghouse” annotations were not provided to pilots during the execution of the test, only in the prior “map study.”

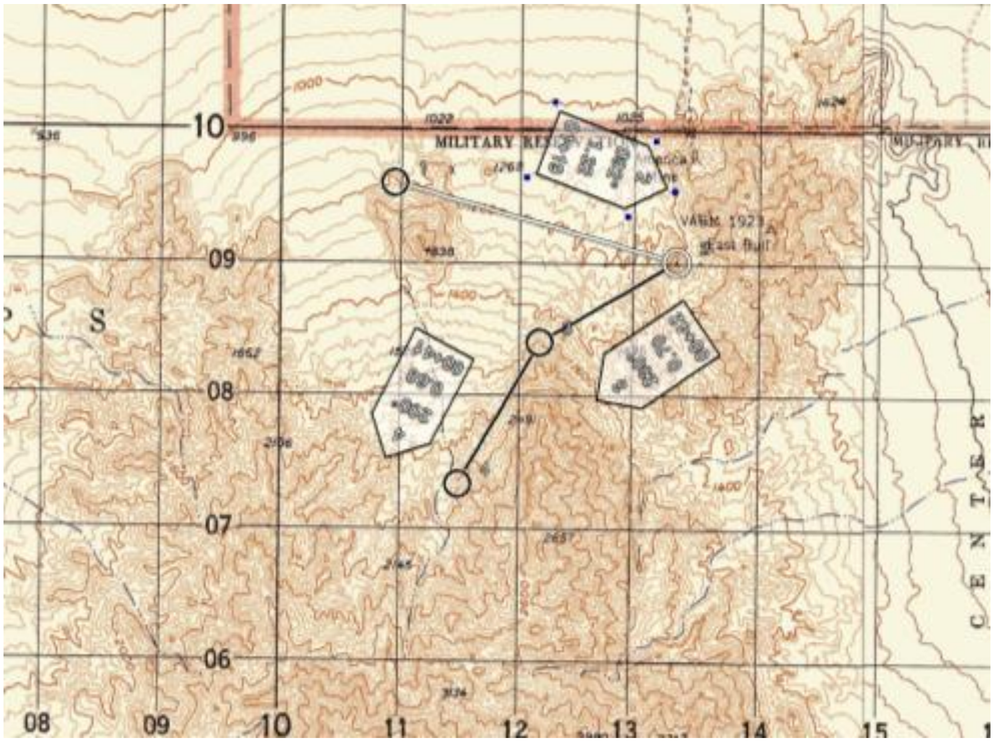

Figure 2. Map of the practice route that participants used for map study. This view shows waypoints 1–4, and the according ‘doghouses’ which give the pilot distance and timing information enroute.

The first navigation route where data was collected was designed to ease the participants into the experiment. Figure 3 shows the intended route of flight for the route. For each scenario the participants begin the route exactly on the first waypoint heading directly to the second waypoint. Approaching waypoint two, there was terrain rising off the nose of the aircraft with a low level wash to the right. After reaching waypoint two, participants had to make a 90-degree turn to the right across the wash to the entrance of a valley at waypoint 3. The valley at waypoint 3 can be misperceived because there was similar valley that leads to the West abeam waypoint three. Participants had to reference their heading to make sure that they are heading down the correct valley, or could also notice that they had to choose the valley furthest to the right. The leg after waypoint 3 follows the valley until it reaches a saddle in the terrain followed by a drop off indicating waypoint 4. The route from waypoints 4 to 5 follow low level terrain to the furthest Northern tip of the higher terrain at waypoint 5. Heading towards waypoint 6 there was a

large chance of misperceiving terrain if the participants were not using the available visual cues. Along this leg, several valleys resemble the one at waypoint 6. Participants had to realize that waypoint 6 is abeam a small hill. Waypoint 7 also had a chance to be misperceived because of a lack of significant terrain in the area. Participants had to be cognizant that once they cross a valley on the leg from 6 to 7, that waypoint 7 is just on the other side. Also if participants miss waypoint 7 they have to recognize the limiting feature of the large flat landscape soon after waypoint 7. Waypoint 8 should be easily recognized if the participant remained close to track because it is the only large hill with little terrain around it. A subject matter expert believed that approximately half of the participants would be able to complete this route without any help from the proctor.

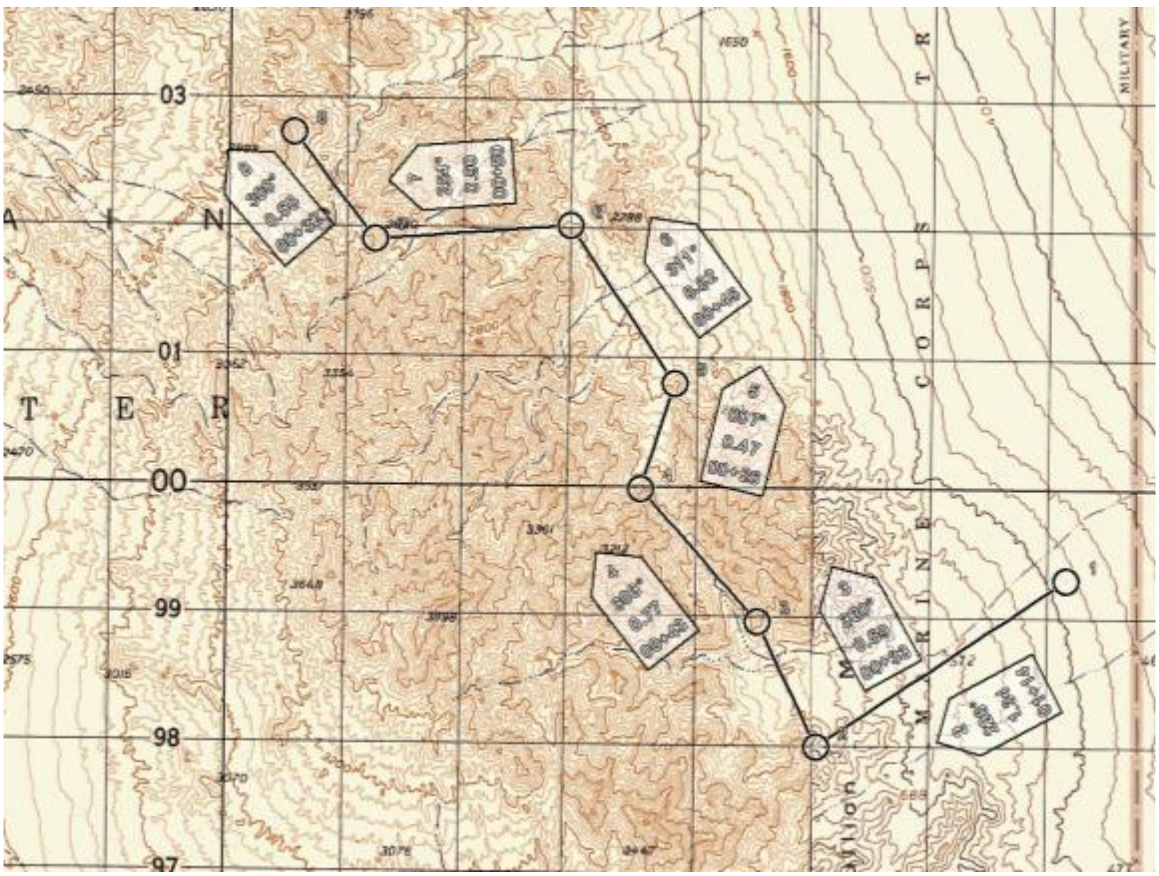

Figure 3. Map of navigation route 1. This type of map was also used for map study. The features of this route that are noteworthy are that it follows easily marked valleys. Also, note that there are no large heading changes.

The second navigation route was designed to task saturate the pilots to a level where they would stray off-course. To achieve this, navigation legs passed through heavily mountainous terrain, making it hard for the pilots to maintain good navigational checkpoints. This route also required turns in excess of 90 degrees. These turns also made it hard for the pilots because it required them to continuously search for new landmarks along the route. Figure 4 shows the intended route of flight for the second route. In this route, waypoint 2 was identifiable because it intersects rising terrain in the first large valley. The leg from 2 to 3 follows a valley up to a ridge at waypoint 3. This ridgeline can be misperceived if the participant does not follow the track because of other similar high terrain in the area. Misperception can then lead the participant to track down the wrong ridgeline to waypoint 4. Waypoint 4 is also difficult to distinguish because of surrounding similar terrain. Much of these misperception errors due to similar terrain were solved with the large North-South running valley which contains waypoint 5. Navigation from point 5 to 6 follows the valley and ends at the entrance to the valley at waypoint 6. After waypoint 6 participants had to make a left hand turn to waypoint 7 at the entrance to a Northeast running valley. Waypoint 7 can be easily misperceived because there is a similar Northeast running valley to the East of point 7. Participants had to make sure that they took the first valley entrance and not the second. Waypoint 8 was also difficult due to other similar high terrain in the vicinity. After hitting waypoint 8 at the mountain peak, participants had to make a right hand turn to waypoint 9 to the East. Waypoint 9 is located along a valley in low level terrain that has the possibility to be overlooked, but was limited by the flat terrain to the East of this point. The leg from 9 to 10 also could be misperceived by a similar adjacent valley to the East of it. It was believed that only a small percentage of the participants would be able to track on-course throughout this route.

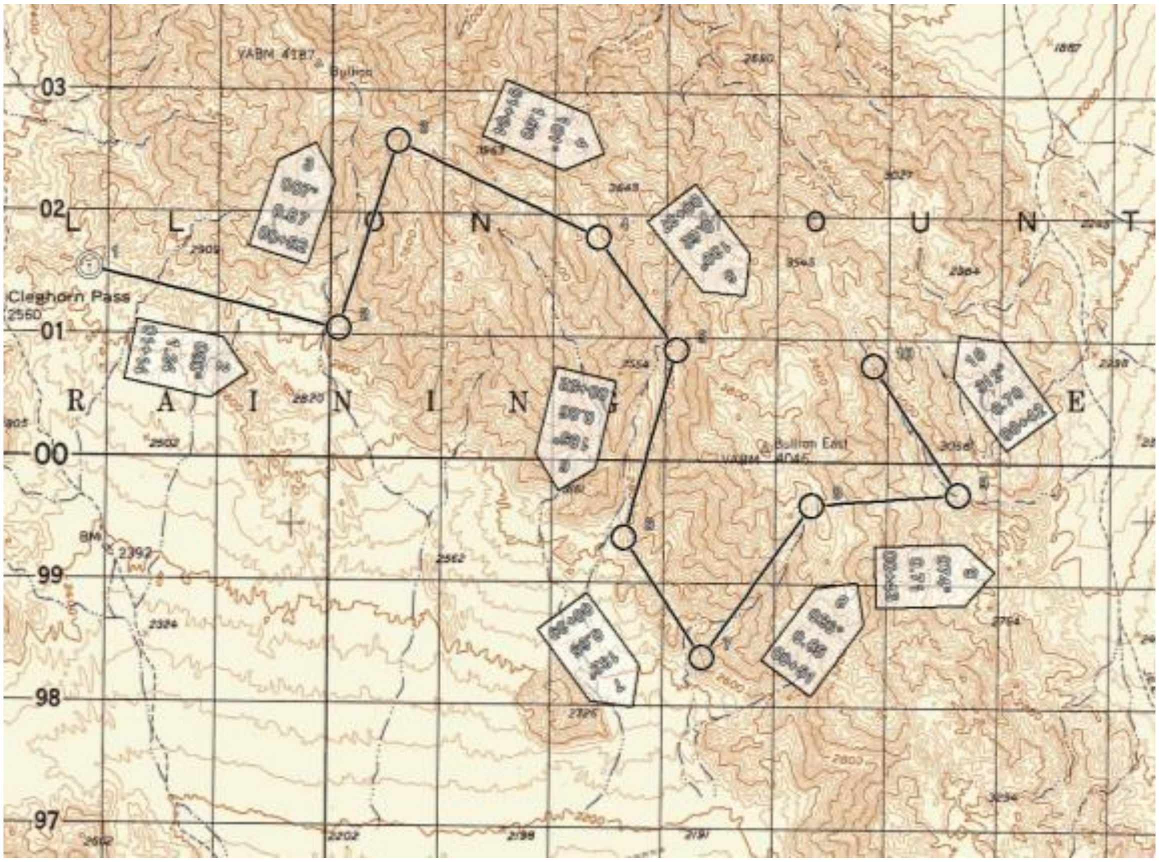

Figure 4. Map of navigation route 2. Note the challenging turns throughout and potential for overflying WP 3 and 5 and similar valleys at WP 7 and 9

The two autonavigation routes were based off the route used in Sullivan (2010) shown in Figure 5. It was during this experiment that over half of the participants misperceived the valley A as waypoint 6, and a large number of participants had problems locating waypoint 9. These autonavigation routes were designed in hopes of determining the reason why participants in Sullivan et al. (2010) did not realize they were off-course once they made their mistake.

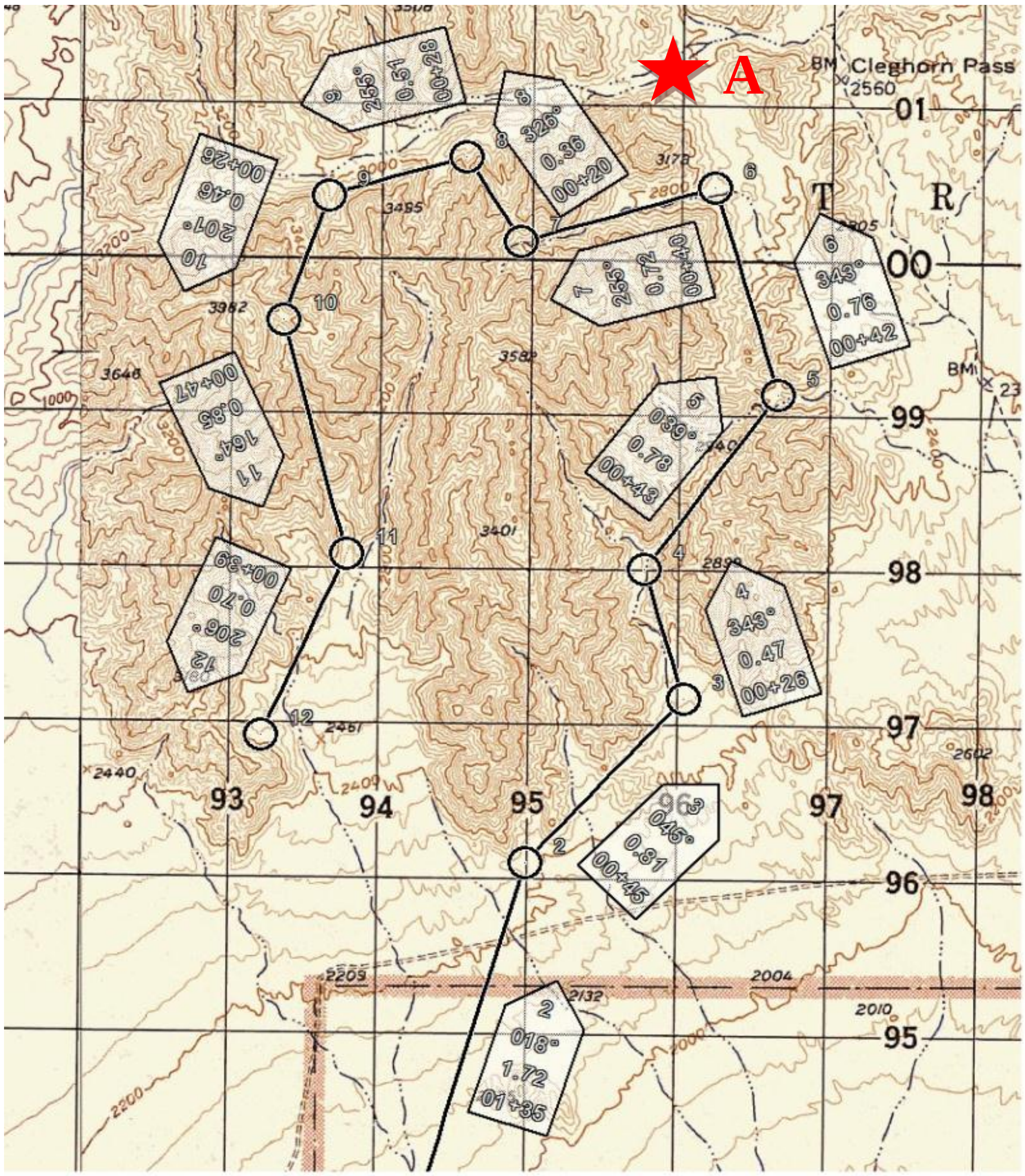

Figure 5. Map of the navigation routes used in Sullivan (2010).

The first autonavigation route, Figure 6, consisted of waypoints 3 through 9 of the route from Sullivan et al. (2010). The autonavigation flight path closely resembles what some of the participants flew in Sullivan's experiment. They went right by waypoint 4, and flew down the wrong valley, i.e., valley A. Instead of realizing they were off course,

they continued to fly, ending up to the North of the intended route. This thesis looks to understand why the participants were misperceiving this segment of the route.

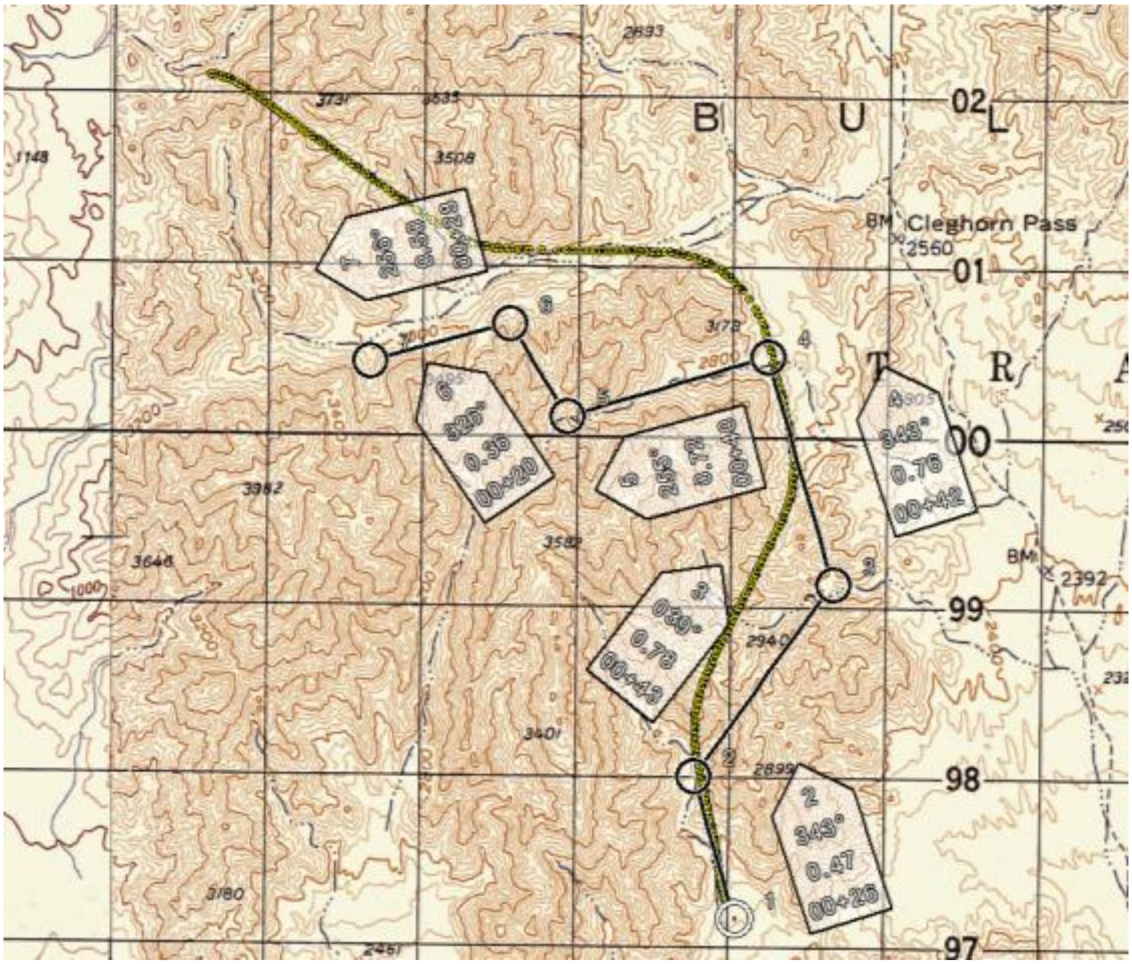

Figure 6. Intended (black) and actual (yellow) first autonavigation route

The second autonavigation route resembles the second half of Sullivan's (2010) route (Figure 7). The actual flight path of route also resembles what some of the participants of Sullivan's (2010) experiment flew. This flight path is considered very difficult to follow once the aircraft turns to the South after waypoint 4 because pilots are navigating through high terrain that can be easily misperceived.

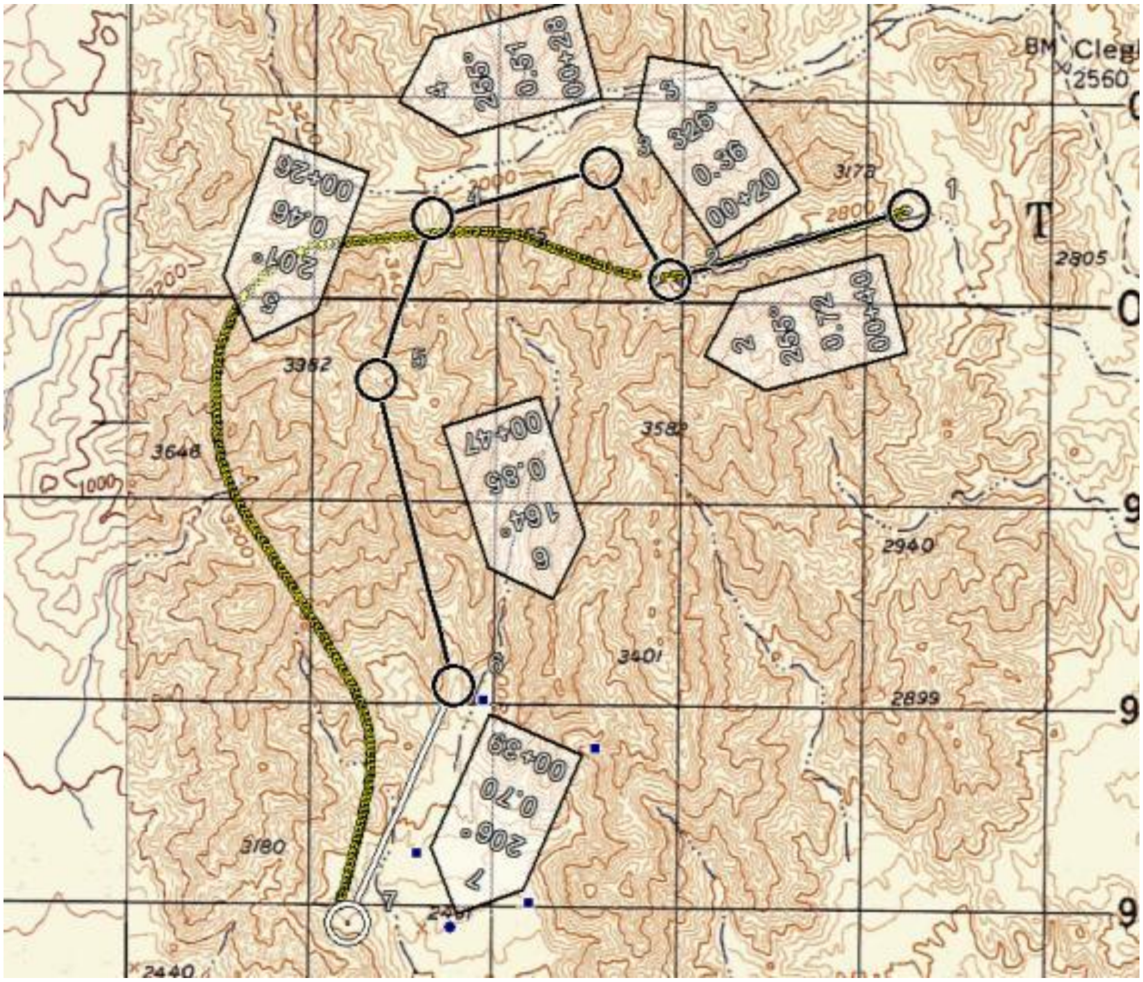

Figure 7. Map of the second auto navigation route. Intended (black) and actual (yellow) second autonavigation route

3. Performance Measures

The measures collected in this experiment were classified into two categories, independent and dependent. The independent variables were based on demographic and experience, while the dependent variables were navigation performance and confidence.

a. Data Collection

The best way to access navigation performance is to combine how accurately the participant navigated through the route and compare it to their confidence or perception (Sullivan, 2010). Finding the accuracy of navigation is relatively easy to calculate, and was one of the measures used in Sullivan (2010). On the opposite end of

the spectrum is confidence. Confidence has considerably more variance than accuracy, and is difficult to measure a benchmark value. It is likely that the participants would have a different baseline and range of confidence (Orbán, 2008). The question is how to best measure a participant's confidence. Ideally, confidence assessments should be collected and updated constantly throughout the navigation route. The participant could only really do this with verbal protocol. The biggest challenge is that there is poor standardization between participants. Some people are more verbal than others, and it is common that people are less likely to say when they are wrong then when they are correct. In addition, verbal protocol drops off when a participant is in a high cognitive workload. For these reasons, Sullivan used post route questionnaires to determine confidence throughout the route. The biggest problem with the post route questionnaire is that participants quickly forget their true confidence feelings after the fact, and are likely to reduce their confidence if they found themselves ultimately getting lost during the simulation.

This experiment was meant to collect accurate confidence data during the navigation process without the disadvantages of verbal protocol or post route questionnaires. One of the hurdles of collecting this data was to avoid interrupting the navigational flow for the participants. This means that large breaks were minimized in order to gather the most realistic data. Break times were reduced by integrating a user-friendly confidence application. The route was paused at 20 to 40 second intervals and the participant was asked to pinpoint their perceived location on the map and to assign a confidence measure to their perception. Pause break times were also minimized by informing participants that the breaks were to analyze their stream of consciousness while navigating, and should take about five seconds and not more than ten seconds. The break times were not to be used to readjust their position by getting additional time to look at the map and the OTW displays.

b. Independent Variables

Independent variables were collected from the background questionnaire that included demographics and expertise. Total flight hours, overland flight hours,

participation in similar past experiments, and experience with low-level and desert low-level navigation were used to group and rank the participants for analysis.

c. Dependent Variables

There were two major dependent variables used for analysis; confidence and the distance from the actual and perceived helicopter position. Confidence was based on a zero to 100 percent scale. The error in perceived location was derived from the great circle distance between the actual latitude and longitude position of the aircraft and the participant's perceived latitude and longitude. The following equation is used because of the Earth's curvature (Gellert, Gottwald, Hellwich, Kästner & Küstner, 1989).

$$d = \arccos(\sin \varphi_a \sin \varphi_p + \cos \varphi_a \cos \varphi_p \cos (\chi_a - \chi_p)) R$$

where d = Error distance (km)

R = Earth's radius at the Twentynine Palms, CA area = 6372.8 km

φ_a = Latitude of the actual aircraft position in radians

φ_p = Latitude of the perceived aircraft position in radians

χ_a = Longitude of the actual aircraft position in radians

χ_p = Longitude of the perceived aircraft position in radians

Euclidian distance would introduce errors, but would be acceptable because the distances involved in this study are minimal compared to the curvature of the Earth.

4. Apparatus

a. Display

The participants of the experiment had three different displays on two monitors. The out-the-window display was located directly in front of the participant and is shown in Figure 8.

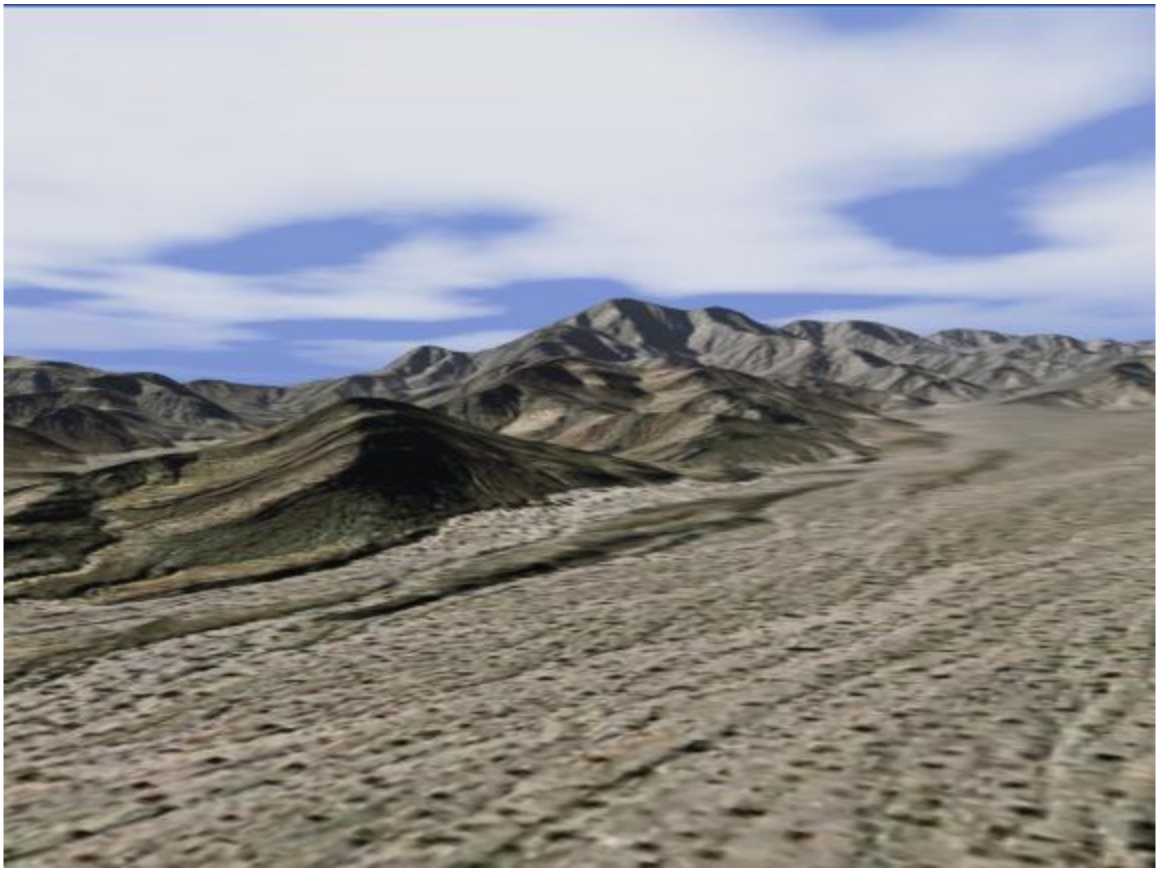

Figure 8. Example of the out the window (OTW) view that the participants saw in the experiment.

The map used for this experiment is the 1:50K topographical land map (TLM). This type of map is used in the training commands for overland navigation, terminal area maps for operational missions, and orienteering. This map is also a good fit for our experiment because the grids on the map are one kilometer in length, giving the participants a quick reference on distance; we believe that this is the map that many of our subjects would choose if they were able. 1:50K TLM also provides in-depth terrain elevation data. Because cockpit map displays vary widely among the different helicopter platforms, this 1:50 TLM was used both in map study and during the simulation. The map display did not have the doghouse information on it, as they would normally have when operating in theater, forcing the participant to visually navigate through the route, and use less emphasis on instrument navigation. The cockpit instrument gauges were selected to resemble standard military gauges, giving the participants with prior aviation

experience a realistic environment, yet kept the instrument cluster simple enough for participants who have limited experience with these gauges. Therefore, the experiment only used a constant running clock, heading indicator, barometric altimeter, and radar altimeter (note: Altitude was fixed at 150' AGL for the experiment). Adding all of the instrument gauges may have made the experiment more realistic, but that could also give an advantage to aviators who have experience with that cockpit layout. This simplified instrument cluster was adequate to complete the navigation routes, and was intended to be used as a backup rather than as the primary navigation tools.

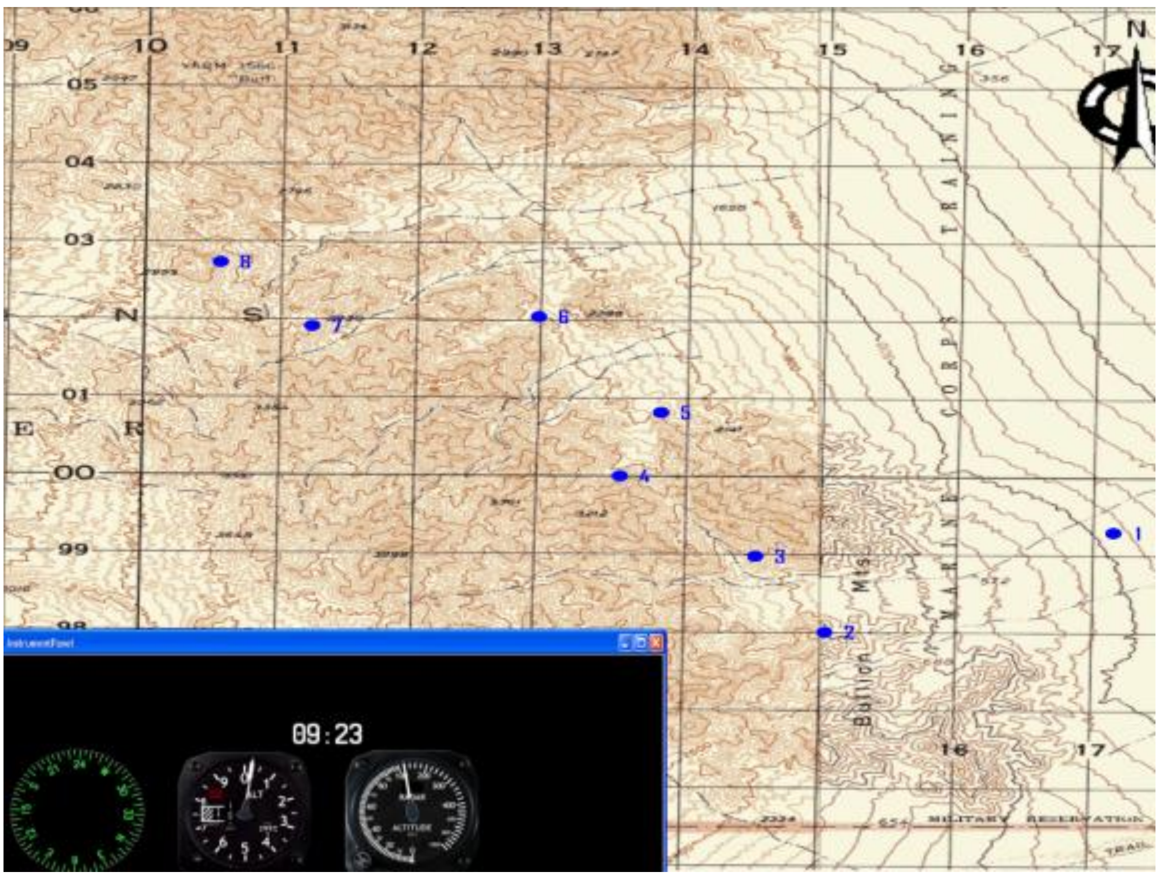

Figure 9. Screen shot of the map and instrument cluster seen by the participants during the experiment. No doghouses are provided during the experiment.

b. Control

As mentioned previously the PNAC is usually the one who is in charge of navigation. The PNAC give verbal navigational commands to the PAC. This brings

about the standardization issue for the experiment. To limit the discrepancies of verbal communication, the participant would be required to navigate and fly for the first two routes. To allow the participant to cover both of these tasks, the aviating task had to be simplified. This simplification was achieved by using autopilot for altitude hold and constant airspeed. This altitude was set to 150 feet AGL and airspeed was set to 65 kts. This means that the only required inputs into the simulation were left and right roll. The roll was executed using a joystick resembling a helicopter cyclic. Navigation using this joystick required a small workload, allowing the participant to concentrate on navigation and not pilotage.

c. Flight Simulation

The setup of equipment for the simulation involved a cockpit style seat with a joystick mounted in between the participant's legs. The joystick placement, look, and control are similar to a helicopter cyclic. The joystick allowed the participant to roll the aircraft in the lateral direction and pitch (up and down) without corresponding changes in altitude and airspeed, and gave the participant the ability to look up and down. A computer mouse was mounted to the right side of the seat for the participant to pinpoint their location on the digital map and adjust their confidence. Directly in front of the participant was the OTW monitor with a 110cm by 61cm display. The OTW monitor was placed four feet from the s participant and covered a 65-degree field of view (FOV). At a 130 degree right offset towards the participant from the OTW display was an 88.5cm by 50cm display used for the map and instrument panel. The display map was a 1:50K topographical land map (TLM), the same type as the participant s used for their map study. On the map were labeled blue circles representing numbered waypoints. The map was pointed North at all times because when the map moved automatically with the heading the aircraft it became very disorienting to the pilot. The instrument panel contained a heading indicator that was typical of Navy H-60 displays. Next to the heading indicator was a typical barometric altimeter followed by a radar altimeter. Above these gauges was a constant running digital-style elapsed time clock. This clock started when the simulation program started and did not stop, even when the simulation was paused, until the route was finished.

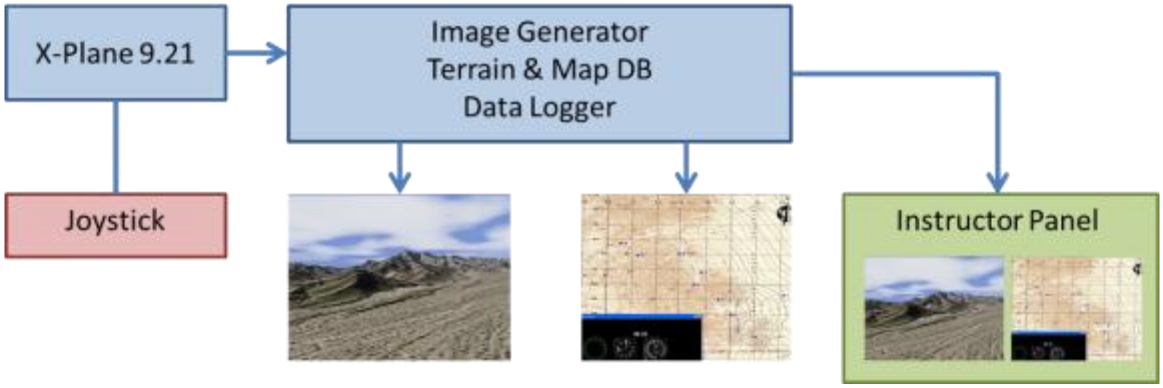

Figure 10. Schematic Diagram of Experiment Setup, Joystick input is read by X-Plane and initiates the Image Generator, which then displays the OTW, map, and instrument outputs to the participant and instructor.

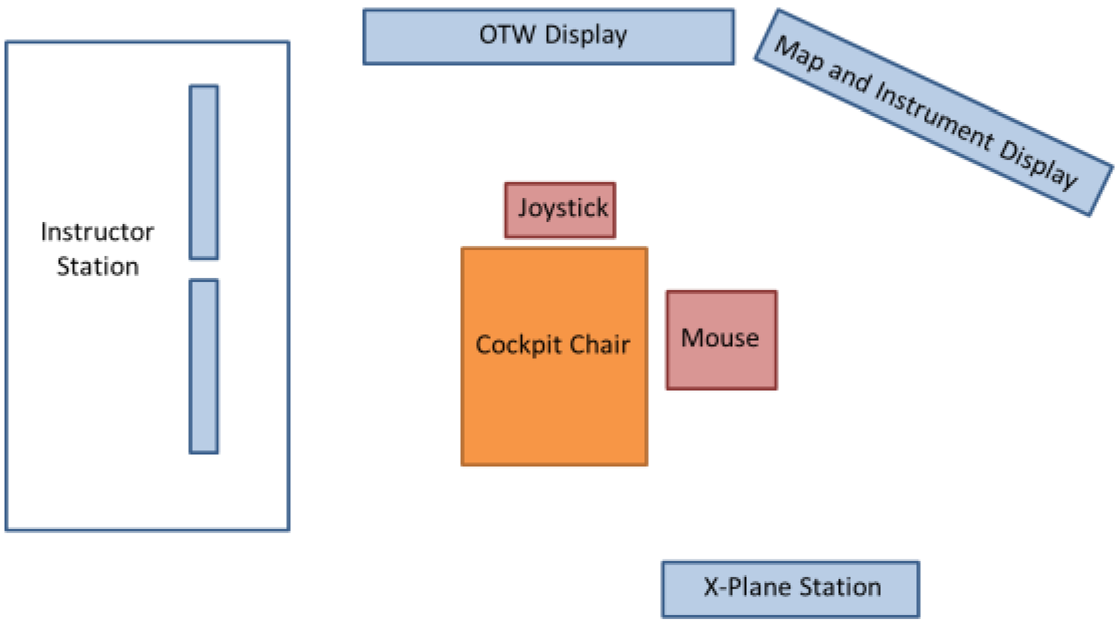

Figure 11. Equipment layout showing the location of participant, instructor, displays, and software.

The software used to run the simulation was Image Generator, Terrain & Map D8, and Data Logger by Delta3D and OpenSceneGraph. These programs used inputs through X-Plane 9.21rc2, a commercially used flight simulator. The software coverts the X-Plane data into the OTW and map views based on the participants inputs. The X-Plane model was set using the Fokker Eindecker E.I airframe with a modernized autopilot and GPS flying at 5,000 mean sea level (MSL) and 65 knots. This airframe was

chosen because of its ability to fly at slow speeds and not stall. The image generation PC takes the X-Plane position information but changes the altitude so that the participants see an altitude of 150 feet AGL. This altitude remained fixed throughout the route and maintained obstacle clearance in the mountainous terrain. Moving the joystick up and down did not affect the pitch of the aircraft, but did allow the participant to look up and down. The roll of the aircraft was completed with left or right joystick inputs. This put the aircraft in coordinated turns. The software also updated the instruments to correspond with the current flight profile.

The first two routes required participant roll inputs to navigate through the route, while the last two routes were flown on autopilot. The autopilot was set in X-Plane to follow a preselected route. The participant did not have roll control but had the ability to look up and down on the screen with forward and back control movement.

d. Confidence Application

Confidence App Software was created in order gain useful confidence output data. This program allowed the participant to click where they perceived to be on the map display. After the participant right clicked on the map, a red dot showed on the screen and a confidence scroll bar appeared. This confidence bar allowed the participant to rate how confident they were of their perceived location. This bar ranged from 100, very confident, to 0, very lost. After the route was complete, the software also created a CSV file that contained the elapsed time of when the participant made his location estimate, the actual helicopter latitude and longitude, the participant's estimated latitude and longitude, and the participant's confidence on their perceived location.

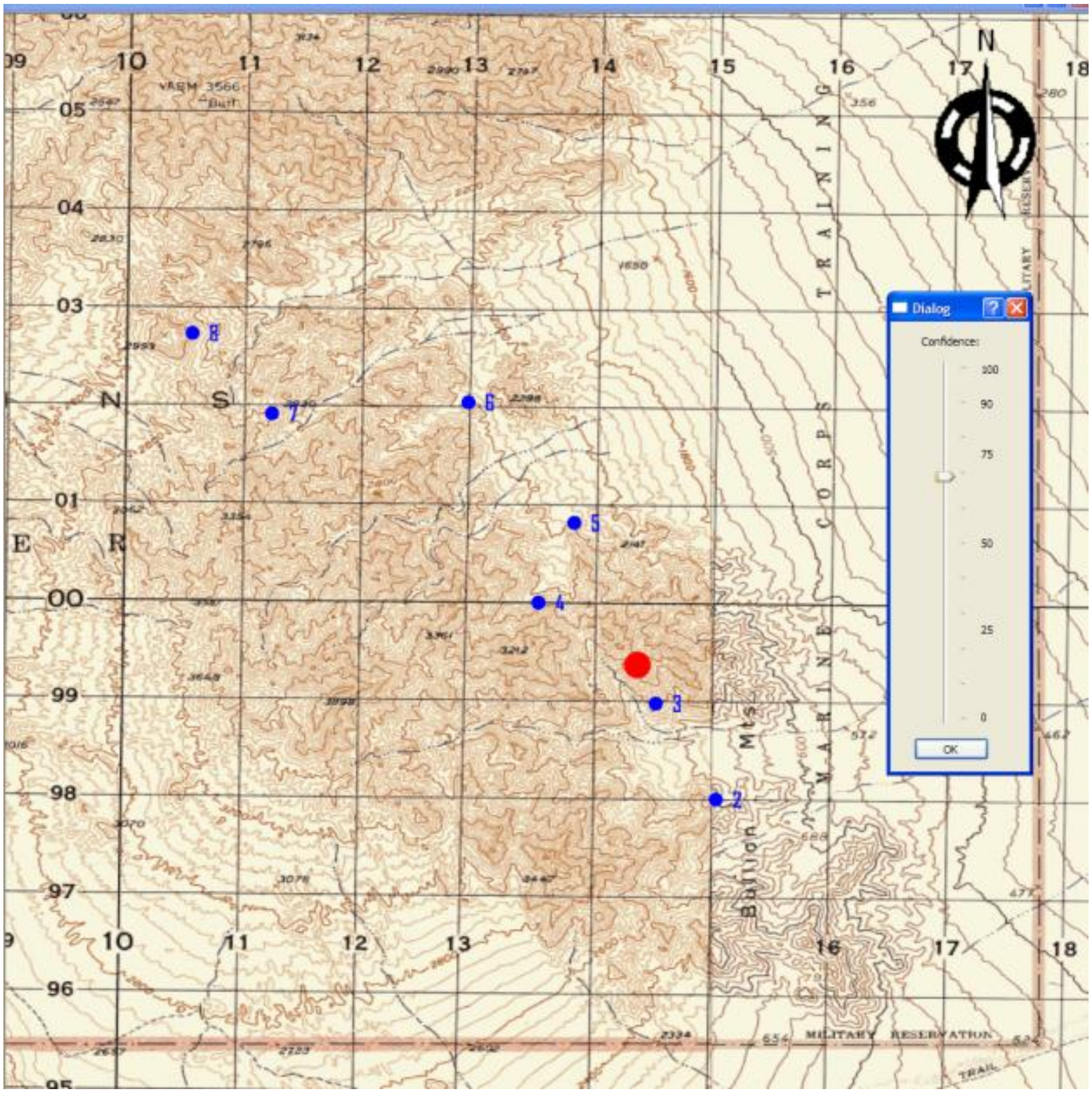

Figure 12. Snapshot of the Confidence App. Red dot is the participant's perceived location and confidence scroll bar from 0 to 100.

5. Procedures

Participants were introduced to the experimentation lab with an IRB approved welcome script (Appendix) that notified the participant of the focus of the study, brief overview of what will be expected out of them, rules of the lab, and the voluntary nature of the study. The participants were given an informed consent form, also listed in Appendix, to read and sign. The form reviewed the minimal risks, the voluntary nature, the benefits, and confidentiality of participating in this experiment. After the informed

consent, the participant was given a questionnaire relating to their flying experience and background (Appendix). The background questionnaire included basic demographics, familiarity of the simulation-operating environment, experience with overland navigation, flight hours, and time since last flight. This data was collected to help group the participants for analysis.

Once the participant completed the background questionnaire, they were given a familiarization of the experiment; including the flight parameters of the helicopter, what is contained on the video screens, joystick control, and how to use the confidence feature of the simulation. Once the participant seemed comfortable with how the simulation would run, they were given a map of the practice route. This was an 8x11 map printed from Falconview. The map was a 1:50K TLM, just like the one that they would see on the monitor. This map was doghoused, with the waypoint number, distance in nm, time to fly the leg, and total elapsed time. This paper map was only allowed during the map study, and not during the flight portion of the simulation. The participant could only use the map on the monitor, which included numbered waypoints, during the simulation. The participants were given unlimited time to review the practice map before flying the simulation. The practice simulation was four waypoints long on an easy route. One of the main objectives of the practice route was to make the participant comfortable with the flight profile and monitor views, along with getting a solid grasp of using the confidence program. This route was paused roughly every 30 seconds for the participant to point out their perceived location on the map, and their confidence level. The participants were given some navigation assistance from the proctor if they were lost. Once the participant completed the route, they were asked if they were comfortable with the simulation and programs. If necessary they were allowed to have extra practice flying the helicopter if they were not comfortable.

After the completion of the practice route, the participants were tasked with completing four navigation routes where data was collected. In the first two routes, the participants were providing roll inputs while flying, whereas the last two routes were flown on autopilot. The first two routes began with a map study period of three minutes, in contrast the last two map study times were two minutes. Map study times were limited

to provide increased difficulty by limiting the amount of headings and timings on the route, and to keep the experiment under an hour in duration. The last two map study times were less because the routes were shorter, and the helicopter was on autonavigation, reducing the task load on the participant. Before executing the autonavigation route, the participants were also given a scenario. In this scenario, the participant simulates flying with a new pilot in the squadron who is responsible for the navigating and flying. Both the new pilot and the participant must fly in an area where they have never been. The new pilot is supposed to follow the route, but there is a chance that they can get off-track. The scenario informs the participant that the intended route is not necessarily what the new pilot will fly. Once the map study was complete, the participant conducted the navigation portion of the simulation. During the first two simulations, the route was paused about every 40 seconds. 40 seconds was not a hard number because the evaluator wanted to minimize pausing during turns. Pausing during turns can be disorienting to participants, and it is hard to remember the amount of bank they had after they finished the pause. During the second two simulations, the pause points were in the same location for each participant, and happened between 20–40 seconds. Again, these pauses occurred during level flight. After the completion of each of the navigation routes, the participants were given a post task questionnaire (Appendix). It questioned whether the participant felt they strayed off-course, misperceived terrain, and asked what they could have done differently to remain on-course.

Once all four routes were completed, the participants were given one final questionnaire (Appendix). This questionnaire covered topics on why they believe pilots get lost, what they do if they sense they are not on-course, and what they think their confidence level during navigation is. This questionnaire allowed for participant grouping based off similar responses. The participants were asked to add any additional comments, and the evaluator asked other pertinent questions to give insights on why they misperceived terrain on the route and confidence levels.

6. Participants

To participate in this experiment the participant needed to have overland navigation training. Participants for this study were recruited from the Naval Postgraduate School student body and faculty. Recruitment was completed through an IRB approved E-mail sent to Operations Research and Modeling, Virtual Environments and Simulation (MOVES) students. In addition, recruitment was done through word of mouth and using past experiment participants.

There were a total of 15 male and female participants ranging from 27 to 41 years of age, with an average of 36 years with a standard deviation of 4.8. Total flight hours ranged from 0 to 2,500 with an average of 1,431 and a standard deviation of 803.5. Total overland hours ranged from 0 to 2,000 with an average of 870 and a standard deviation of 634.2. There were eleven U.S. Navy, four U.S. Army participants, and one Hellenic Air Force participant.

III. ANALYSIS OF EXPERIMENTAL DATA

A. VARIABLE DEFINITAION

This section covers the variables that were used for data analysis and their definitions.

1. Confidence (CONF)

Pilots' confidence was self-reported using the Confidence App, i.e., participants rated their navigation confidence from 0 to 1 for each pause point. The CONF is defined as confidence measurement between 0 and 1, where 0 indicates the lowest confidence and 1 the highest confidence. CONF_BIN is a variation of CONF coerced into a binary variable. The CONF_BIN is defined as

CONF_BIN = High if CONF $\geq$ 0.5

Low if CONF < 0.5

The threshold of 0.5 was chosen for the CONF_BIN variable because it was the numerical midpoint of the CONF range. This midpoint was easily defined on the Confidence App, making it a likely division between high confidence and low confidence. If a participant believed there was a good chance their perceived location is not close to the actual location they would not choose a confidence level over 0.5.

2. Error (Correctness)

To measure the navigation performance of the participant, error distance was solved. This error distance was defined as the great circle distance (Gellert, 1989) from where the subject perceived they were compared to where they actually were during the pause points.

ERROR1 = great circle distance between perceived and actual location in km

$= \arccos(\sin \varphi_a \sin \varphi_p + \cos \varphi_a \cos \varphi_p \cos(\chi_a - \chi_p))\, R$

where R = Earth's radius at the Twentynine Palms, CA area = 6372.8 km

φ_a = Latitude of the actual aircraft position in radians

φ_p = Latitude of the perceived aircraft position in radians

χ_a = Longitude of the actual aircraft position in radians

χ_p = Longitude of the perceived aircraft position in radians

Similarly, the second type of error that was calculated was the distance between where the participant perceived they were compared to the *intended* route of flight.

ERROR2 = great circle distance between perceived and planned location in km

$$= \arccos(\sin \varphi_i \sin \varphi_p + \cos \varphi_i \cos \varphi_p \cos (\chi_i - \chi_p))\, R$$

where R = Earth's radius at the Twentynine Palms, CA area = 6372.8 km

φ_i = Latitude of the planned aircraft position in radians

φ_p = Latitude of the perceived aircraft position in radians

χ_i = Longitude of the planned aircraft position in radians

χ_p = Longitude of the perceived aircraft position in radians

The next derived variable, NAV, took the ERROR1 distance and turned it into an indicator variable to state whether the participant stayed within a certain threshold/boundary. Pilots were instructed to stay within .5 km of the route; we buffered this to be .75 km.

NAV = On-track if ERROR1 $<$ 0.75 km

Off-track if ERROR1 $\geq$ 0.75 km

The 0.75 km distance for obtaining the NAV variable was used because participants were told prior to their navigation tasks that they should be confident in their perceived location if they were within 0.5km of their actual location. The 0.75 km gave the subjects an additional 0.25 km error distance because it is difficult for pilots to recognize if they fell within the 0.5 km distance while navigating. This additional error

distance also helped to affirm, without any doubt, that the participant has the wrong perception of their location.

3. Experience

The study also conducted exploratory analysis on the effect of pilot experience. This analysis required defining variables for pilot flight hours, expertise, familiarity with low level desert navigation, and whether the subject participated in a similar past study and consequently may have experienced a practice effect. These variables are shown below.

EXPERTISE = Expert if participants total number of flight hours > 1,000

Novice if participants total number of flight hours ≤ 1,000

PROFICIENT = Yes, if the participant answered Somewhat, Considerable, or Extensive for their experience with low level desert navigation

No if the participant answered Very Little or None

PAT_EXP = Yes, if the subject participated in a similar past study

No, if they did not participate in a past study

B. COMPREHENSIVE NAVIGATION PERFORMANCE

The first analysis of the data related the experiment output to the Sullivan's (2010) modified SDT matrix for assessing navigation skills (Table 1). The experiment focused on the "dangerous" quadrant as defined in Chapter I; the pilot does not realize that they are lost. Table 3 shows the confidence versus navigational error using the CONF_BIN and NAV variables.

Assessing Navigation Performance		**CONF_BIN**		
		Low	**High**	Grand Total
NAV	**Off-track**	7.67% (22.14%)	**26.98% (77.86%)**	34.65% (100%)
	On-track	6.98% (10.68%)	58.37% (89.32%)	65.35% (100%)
Grand Total		14.65%	85.35%	100%

Table 3. Matrix of experimental navigation performance relating CONF_BIN and NAV. Percentages in parentheses are calculated based on Off-track or On-track NAV respectively. Of interest is the bolded area, corresponding to off track and high confidence, or the “dangerous” quadrant.

Table 3 shows that 58.37% of the time during the navigation participants were On-track and had a corresponding high confidence level. This table also shows that only 6.98% of time pilots had low confidence yet still were considered On-track. These percentages reflect that the subject is highly unlikely to misperceive their location when on-track, but the problem arises when the participants were Off-track. Subjects were off-track, yet still highly confident 26.98% of the time during the navigation. This indicates subjects were highly confident about their navigation performance 77.86% of the time when they were off-track. The misperception error is about 3.5 times greater than correct perception when a pilot is off track. This relates to the dangerous section of the matrix where pilots are lost and do not know it, and this is the second largest navigational state of the experiment among four navigational states. It is also in this area where mission failure and mishaps occur due to incorrect navigation. Figure 13 shows the breakdown of navigation performance matrix.

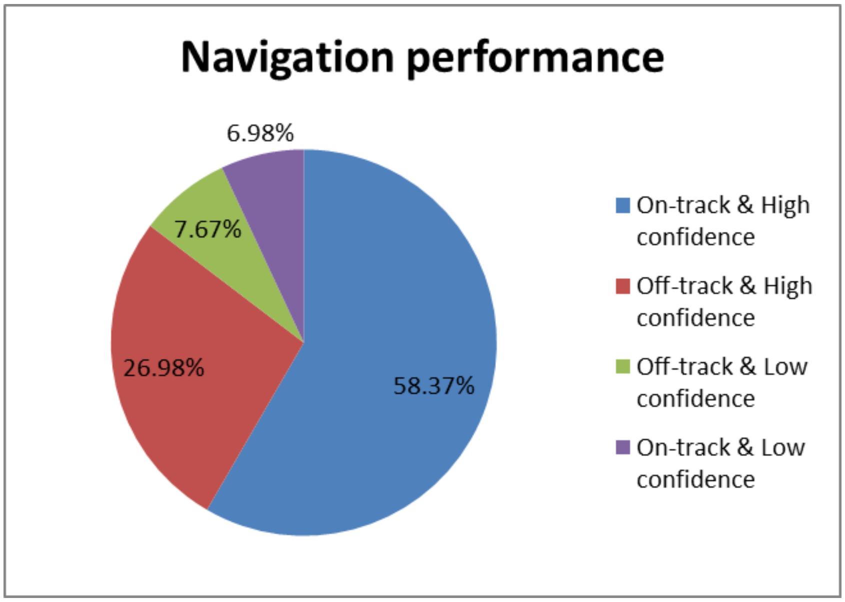

Figure 13. Pie chart of comprehensive navigation performance matrix. Notice Off-track and High CONF is second highest performance state, and greater than 40% of participants were away from 'On track, high confidence,' suggesting that overland navigation is a complex task.

Table 3 is further broken down to see if different routes result in different perception output. Table 4 compares the route and CONF_BIN and NAV.

Assessing Navigation Performance		Route				
		1	2	3	4	Average
NAV and CONF_BIN	**Off-track**	26.6%	28.4%	35.6%	34.8%	30.9%
	High Confidence	**19.5% (73.3%)**	**21.3% (75.0%)**	**31.7% (88.9%)**	**25.8% (74.2%)**	**24.2% (78.2%)**
	Low Confidence	7.1% (26.7 %)	7.1% (25.0%)	4.0% (11.1%)	9.0% (25.8%)	6.7% (21.8%)
	On-track	73.5%	71.7%	64.4%	65.2%	69.1%
	High Confidence	65.5% (89.2%)	65.4% (91.2%)	55.5% (86.2%)	56.2% (86.2%)	61.2% (88.5%)
	Low Confidence	8.0% (10.8%)	6.3% (8.8%)	8.9% (13.8%)	9.0% (13.8%)	7.9% (11.4%)
	Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 4. Matrix of experimental navigation performance for each route comparing navigation performance and confidence. the auto navigation routes (3 and 4) had a lower percentage of route correctness, 73.5% and 71.7% for routes 1 and 2 versus 64.4% and 65.2% for routes 3 and 4, respectively.

Table 4 shows that the confidence and correctness for each route align with the overall breakout. The most interesting fact that Table 4 shows is that the auto navigation routes (3 and 4) had a lower percentage of route correctness, 73.5% and 71.7% for routes 1 and 2 versus 64.4% and 65.2% for routes 3 and 4 respectively. The participants misperceive their location more frequently when control inputs were not required from them. Some explanations for this could be due to complacency, and/or experiment fatigue. During the auto navigation routes, participants seemed to be more relaxed during the navigation and map study. Participants were less likely to be actively tracking the course, which lead them to believe that the aircraft was heading on course. This type of complacency is common in multi-piloted aircraft and can be attributed to mishaps. Also noteworthy is the fact that route 3 had the highest percentage of time in the "dangerous" quadrant. Order effects may explain why route 3 was higher than the other routes. Route 3 could be higher than route 1 and 2 because route 3 was the first time the participant dealt with autonavigation. Additionally, route 3 could also be higher than route 4 because they pilot realized at the end of route 3 that the autonavigation did not follow the intended route of flight, making the CONF on route 4 less than 3. This would correspond to a lower amount of time in the "dangerous" quadrant.

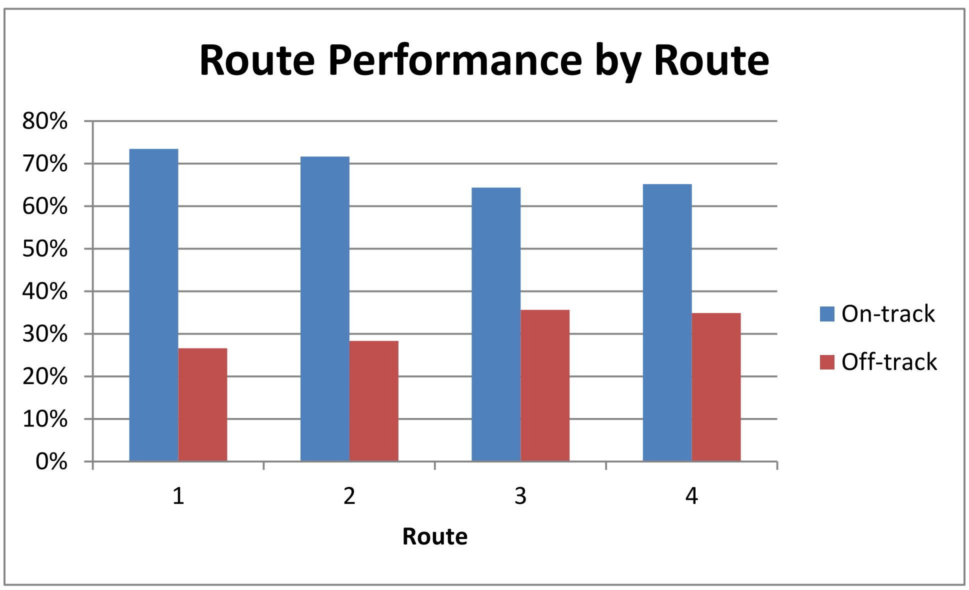

Figure 14. Column graph of navigation performance by route

C. HYPOTHESIS TESTING

We used Spearman's rank correlation coefficient to determine statistical dependence between variables for the first two hypothesis tests. Spearman's rank correlation is a nonparametric measure, and is commonly denoted as ρ (rho). Spearman's rank correlation coefficient is defined as Pearson's correlation coefficient with ranked variables (Myers & Well, 2003) and is given by

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)}$$

where d_i = the difference in rank between confidence and error distance

n = the cumulative number of pause points examined for each route

The significance level, α, was set at 0.05. To avoid confusion, for the remainder of this paper, when we refer to ρ, we mean Spearman's measure.

1. Hypothesis 1: Navigation Error and Confidence is Negatively Correlated, i.e., as Navigation Error Increases, Corresponding Confidence Decreases.

Hypothesis 1 was examined for each route. The average CONF and ERROR1 was computed for each route, and then these averages were tested for correlation. Below are the null and alternative hypotheses.

$H_{01.1}$: There is a positive or no correlation between CONF and ERROR1 for the first route, i.e., $\rho_1 \geq 0$

$H_{a1.1}$: There is a negative correlation between CONF and ERROR1 for the first route, i.e., $\rho_1 < 0$

$H_{01.2}$: There is a positive or no correlation between CONF and ERROR1 for the second route, i.e., $\rho_2 \geq 0$

$H_{a1.2}$: There is a negative correlation between CONF and ERROR1 for the second route, i.e., $\rho_2 < 0$

$H_{01.3}$: There is a positive or no correlation between CONF and ERROR1 for the third route, i.e., $\rho_3 \geq 0$

$H_{a1.3}$: There is a negative correlation between CONF and ERROR1 for the third route, i.e., $\rho_3 < 0$

$H_{01.4}$: There is a positive or no correlation between CONF and ERROR1 for the fourth route, i.e., $\rho_4 \geq 0$

$H_{a1.4}$: There is a negative correlation between CONF and ERROR1 for the fourth route, i.e., $\rho_4 < 0$

Table 5 shows Spearman's rank correlation for each route.

ρ_1	ρ_2	ρ_3	ρ_4
-0.150	0.158	0.036	-0.354

Table 5. Spearman's rank correlation coefficient relating CONF and ERROR1 for each route. Notice that there are not statistically significant values (all p-values > 0.1)

Using a one-tailed test of Student's t distribution at $\alpha = 0.05$ level, we fail to reject $H_{01,}$ $H_{02,}$ $H_{03,}$ and $H_{04.}$ Thus, we cannot claim that navigation error and confidence is negatively correlated for routes 1 through 4. This is a surprising result. One would think that there should be a high correlation between confidence and perceived location.

This result has several implications to real world navigation. When a pilot is confident in their location, it does not necessarily mean that they on course. Knowledge of this fact could help reduce the amount of complacency of the crewmembers who are not actively navigating. This result can also be used a wake-up call for the navigating

pilot. They might reduce their confidence level that they are on track causing them to be more proactive in the cockpit and help notice potential dangers if they are not following the route correctly.

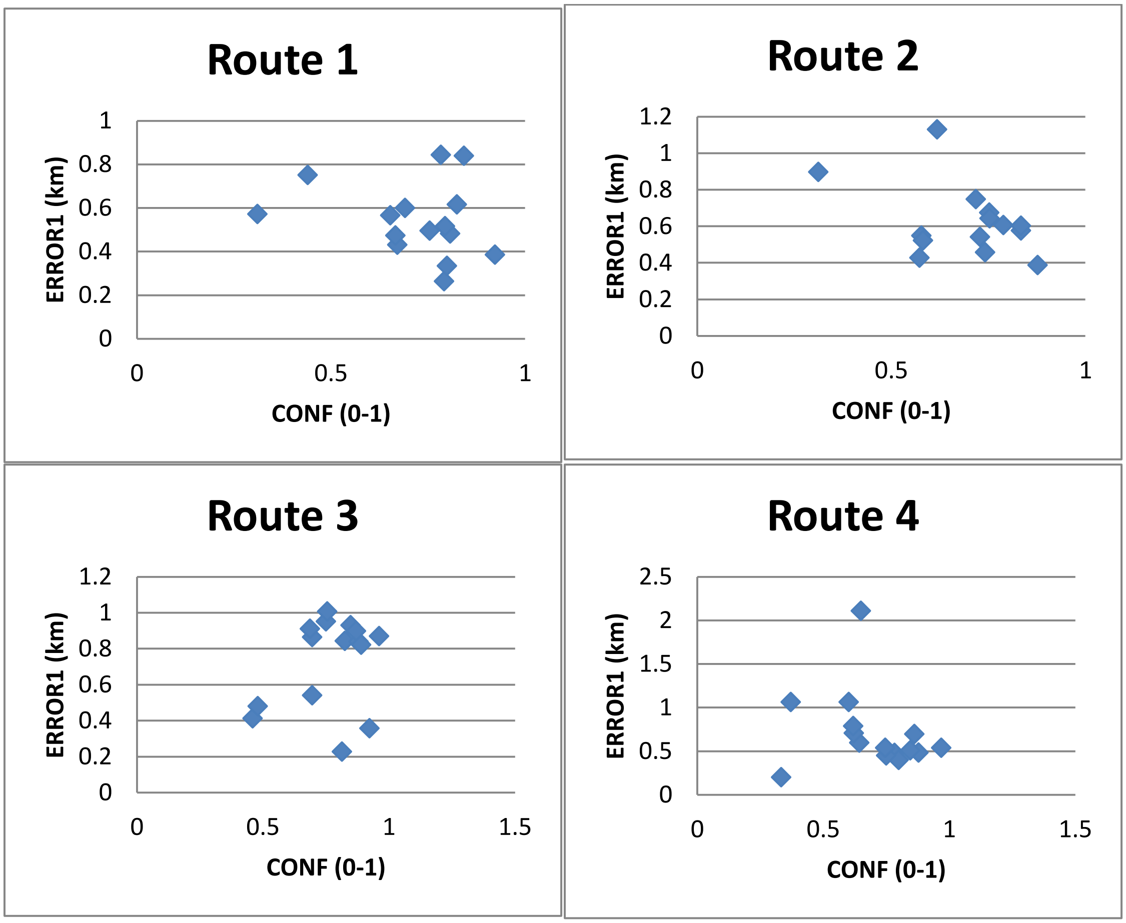

Figure 15. CONF versus ERROR1 for each route. Note there looks to be little correlation between the variables.

2. Hypothesis 2: Distance Between Perceived Location and Intended Route is Negatively Correlated to Confidence, i.e., as the Distance Between the Perceived Location and Intended Route Increases, Corresponding Confidence Decreases.

$H_{02.1}$: There is a positive or no correlation between CONF and ERROR2 for the first route, i.e., $\rho_1 \geq 0$

$H_{a2.1}$: There is a negative correlation between CONF and ERROR2 for the first route, i.e., $\rho_1<0$

$H_{02.2}$: There is a positive or no correlation between CONF and ERROR2 for the second route, i.e., $\rho_2\geq 0$

$H_{a2.2}$: There is a negative correlation between CONF and ERROR2 for the second route, i.e., $\rho_2<0$

$H_{02.3}$: There is a positive or no correlation between CONF and ERROR2 for the third route, i.e., $\rho_3\geq 0$

$H_{a2.3}$: There is a negative correlation between CONF and ERROR2 for the third route, i.e., $\rho_3<0$

$H_{02.4}$: There is a positive or no correlation between CONF and ERROR2 for the fourth route, i.e., $\rho_4\geq 0$

$H_{a2.4}$: There is a negative correlation between CONF and ERROR2 for the fourth route, i.e., $\rho_4<0$

Table 6 shows Spearman's rank correlation for each route.

ρ_1	ρ_2	ρ_3	ρ_4
-0.650*	-0.266	0.011	-0.596*

† p<.10, * p < .05, ** p < .01, *** p < .001

Table 6. Spearman's rank correlation coefficient relating CONF and ERROR2 for each route

Using a one-tailed test of Student's t distribution at $\alpha = 0.05$ level, we reject H_{01} and H_{04}. Thus, we can claim that the distance between perceived location and intended

route and confidence is negatively correlated for routes 1 and 4. This means that the participant has high confidence when they *believe* they are close to the intended route for routes 1 and 4 regardless of their actual closeness. This result shows that there is evidence of biased visual perception favoring their intended location.

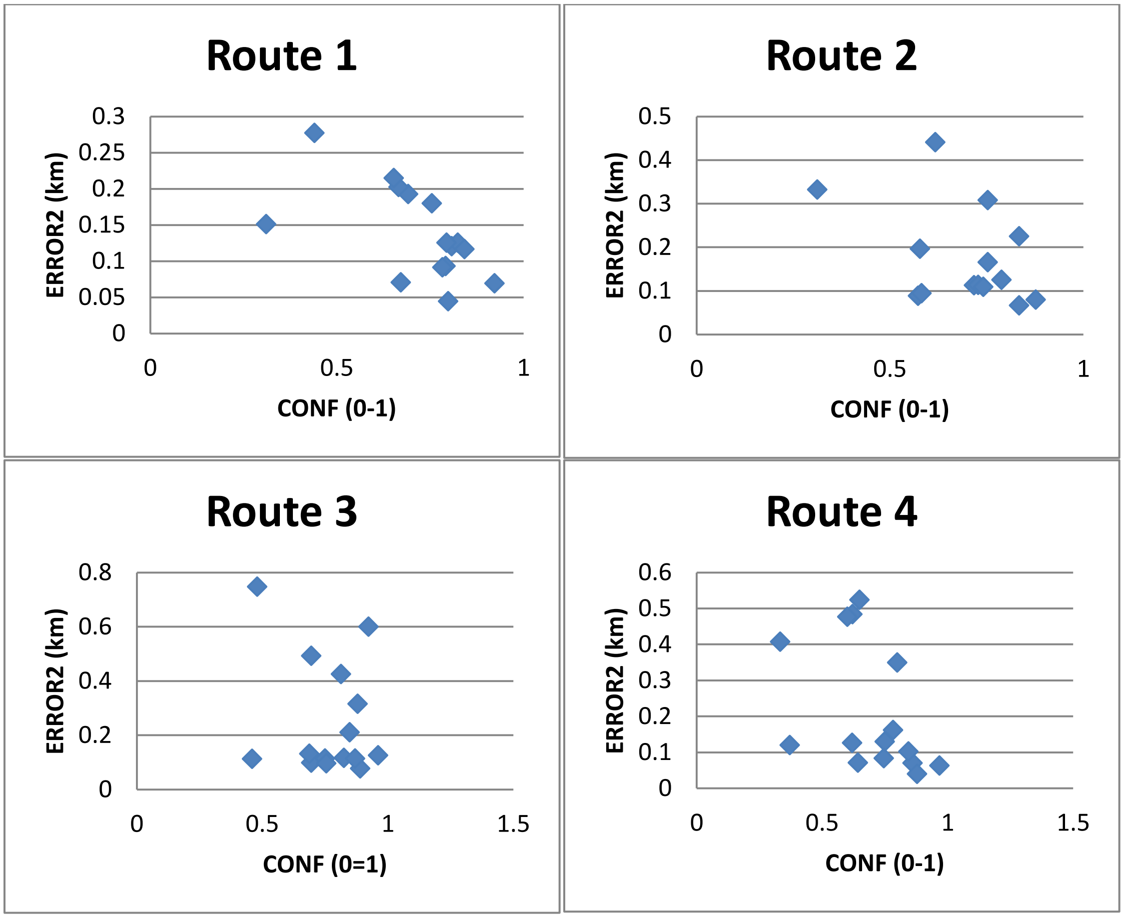

Figure 16. CONF versus ERROR2 for each route. There looks to be some correlation between the variables.

Adding to the ERROR2 and CONF correlation Table 7 shows the average ERROR1 and ERROR2 distance for each route.

Route	Avg ERROR1	Avg ERROR2	% Difference
1	0.5304	0.1311	404.58%
2	0.6337	0.1805	351.08%
3	0.7411	0.2525	293.50%
4	0.704	0.2122	331.76%

Table 7. Average ERROR1 and ERROR2 for each route and the percent difference in the averages.

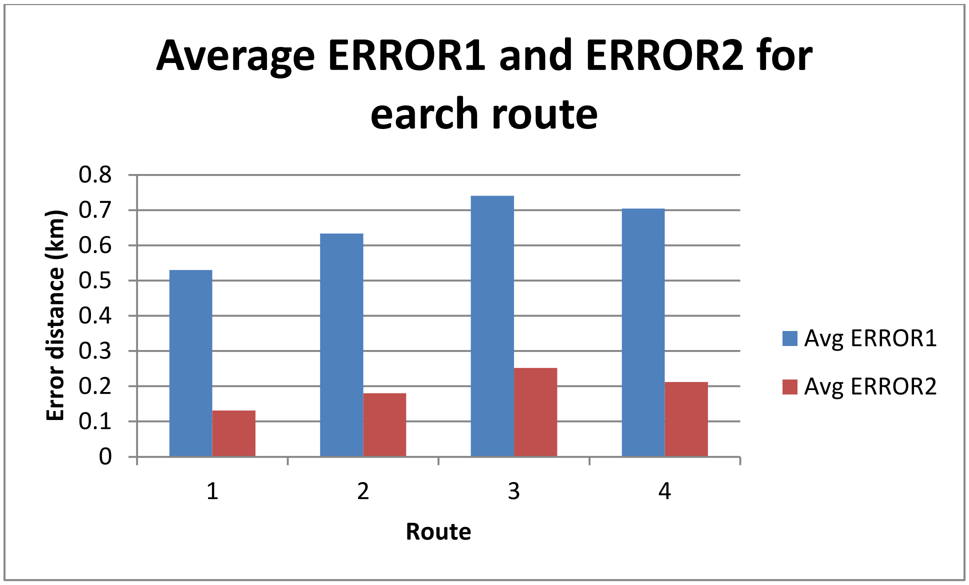

Figure 17. Column graph showing the difference between ERROR1 and ERROR2

Table 7 and Figure 17 show how the participants were biased towards the intended route of flight. ERROR1 was about three and a half times larger than the corresponding ERROR2. Completing a paired t-test between ERROR1 and ERROR2, results in a t-stat of 11.4 and a corresponding p-value of $p < 0.001$. This means that when confused, pilots had a tendency to perceive they were where they were supposed to be, and not defaulting to being further off track than they actually are. This result is again helpful for pilots, because if they know that there is tendency to overestimate their navigational skills, they might reduce their estimation and corresponding confidence.

3. Hypothesis 3: Perception Error Increases the Longer the Participant Navigates, i.e., the Distance Between Perceived Location and Actual Location is Larger at the End of the Route Compared to the Beginning.

$H_{03.1}$: ERROR1 at the end of the route for the first route is smaller or equal to ERROR1 at the beginning of route one.

$H_{a3.1}$: ERROR1 at the end of the route for the first route is larger than ERROR1 at the beginning of route one.

$H_{03.2}$: ERROR1 at the end of the route for the first route is smaller or equal to ERROR1 at the beginning of route two.

$H_{a3.2}$: ERROR1 at the end of the route for the first route is larger than ERROR1 at the beginning of route two.

$H_{03.3}$: ERROR1 at the end of the route for the first route is smaller or equal to ERROR1 at the beginning of route three.

$H_{a3.3}$: ERROR1 at the end of the route for the first route is larger than ERROR1 at the beginning of route three.

$H_{03.4}$: ERROR1 at the end of the route for the first route is smaller or equal to ERROR1 at the beginning of route four.

$H_{a3.4}$: ERROR1 at the end of the route for the first route is larger than ERROR1 at the beginning of route four.

Table 8 shows the t statistics for each route.

$t_{3.1}(14)$	$t_{3.2}(14)$	$t_{3.3}(14)$	$t_{3.4}(14)$
-2.067 p-value 0.0260*	-3.150 p-value 0.0028**	-7.708 p-value 1.05E-06***	-2.816 p-value 0.0069**

† $p<.10$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 8. t- statistics comparing ERROR1 in the beginning of the route and ERROR1 at the end of the route for each route. $\alpha = 0.05$ We reject the null hypothesis in each case, showing that ERROR1 increased at the end of the route.

Table 8 supports the hypothesis that there is a statistically significant difference in ERROR1 at the beginning of the route and ERROR1 at the end of the route. This suggests that perception error gets larger the longer the participant flies. This result can help pilots realize that they might want to reevaluate their perceived location the further along the route they are, and reduce their corresponding confidence in their location.

4. Hypothesis 4: Confidence Decreases the Longer the Participant Navigates, i.e., the Participants Confidence Level is Larger at the Beginning of the Route Compared to the End.

$H_{04.1}$: CONF at the end of the route for the first route is smaller or equal to CONF at the beginning of route one.

$H_{a4.1}$: CONF at the end of the route for the first route is larger than CONF at the beginning of route one.

$H_{04.2}$: CONF at the end of the route for the first route is smaller or equal to CONF at the beginning of route two.

$H_{a4.2}$: CONF at the end of the route for the first route is larger than CONF at the beginning of route two.

$H_{04.3}$: CONF at the end of the route for the first route is smaller or equal to CONF at the beginning of route three.

$H_{a4.3}$: CONF at the end of the route for the first route is larger than CONF at the beginning of route three.

$H_{04.4}$: CONF at the end of the route for the first route is smaller or equal to CONF at the beginning of route four.

$H_{a4.4}$: CONF at the end of the route for the first route is larger than CONF at the beginning of route four.

Table 9 shows the t-test for each route.

$t_{4.1}(14)$	$t_{4.2}(14)$	$t_{4.3}(14)$	$t_{4.4}(14)$
3.105 p-value 0.00234**	2.401 p-value 0.0120*	2.310 p-value 0.0145*	2.902 p-value 0.00401**

† $p<.10$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 9. Student t test relating CONF in the beginning of the route and CONF at the end of the route for each route. $\alpha = 0.05$

Table 9 supports the hypothesis that there is a statistically significant difference in CONF at the beginning of the route and CONF at the end of the route. This suggest that the longer the participant navigates along a route, their corresponding confidence gets lower. This result follows along with hypothesis 3, that the perceived error appears to increase the longer the participant navigates. Pilots CONF is reducing with an increasing ERROR1. Although there is no correlation between CONF and ERROR1, there is a trending effect of CONF getting lower further into the route while ERROR1 is increasing.

D. EXPLORATORY ANALYSIS ON EXPERTISE EFFECT

Analysis was done to see if there was any effect on the results due to experience. This experience was broken down into two categories: expertise effect and learning effect.

1. Expertise Effect

To check the difference between expert and novice pilots, analysis comparing the effect of total flight hours (EXPERTISE) and low-level desert navigation experience (PROFICIENT).

a. EXPERTISE (Total Flight Hours)

CONF, ERROR1, and ERROR2 were analyzed for EXPERTISE on each route. The experiment included 11 Expert and 4 Novice participants. Figure 18 shows the averages of each of the variable with an error bar of a 95% confidence level.

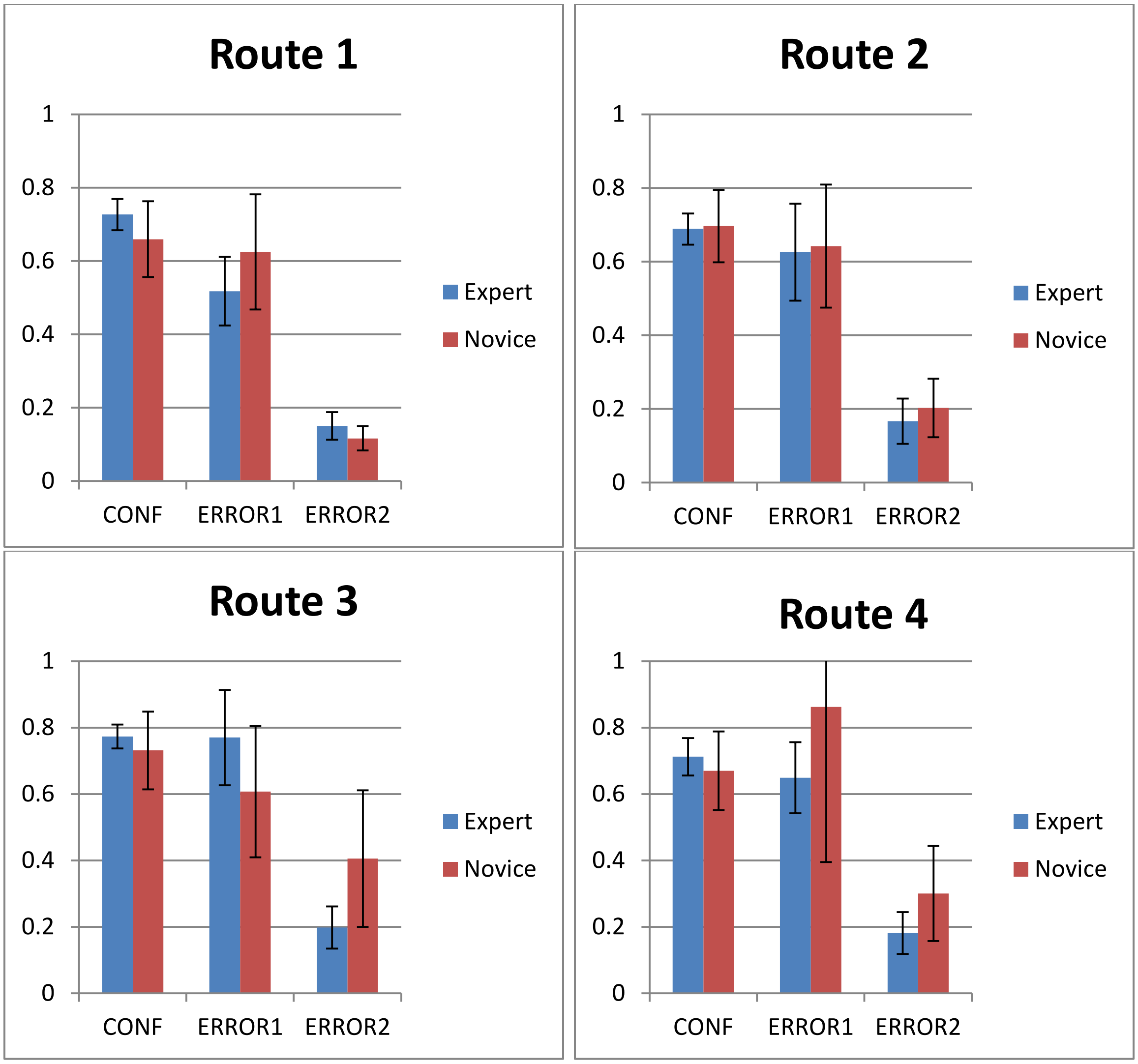

Figure 18. EXPERTISE effect on CONF, ERROR1, and ERROR2 for each route. Error bars are for a 95% confidence level.

Figure 18 shows that there is overlap in confidence levels for every variable on every route. This means that EXPERTISE does not have an effect on CONF, ERROR1 and ERROR2. To further examine the relationship between EXPERTISE and the variables, Student t tests between expert and novice were conducted for each route and shown in Table 10 for an $\alpha = 0.05$.

		Route			
		1	2	3	4
CONF	t_3	0.363	-0.0195	-0.111	0.141
	p-value	0.735	0.986	0.917	0.895
ERROR1	t_3	-0.816	-0.0898	0.547	-0.383
	p-value	0.475	0.932	0.608	0.727
ERROR2	t_3	1.34	-0.538	-1.169	-0.870
	p-value	0.203	0.610	0.327	0.433

† p<.10, * p < .05, ** p < .01, *** p < .001

Table 10. Student t test on EXPERTISE for CONF, ERROR1, and ERROR2 for each route. We do not reject the null hypothesis in any case here, suggesting the EXPERTISE does not have an effect on the experiment.

Table 10 shows that there is no statistically significant correlation on EXPERTISE. This also means that there is also no effect on Expertise for the experiment using t-tests.

The final check to see if EXPERTISE had an effect on the data was to see if Experts and Novices were in the "dangerous" quadrant for a similar amount of time. Table 11 shows the matrix breakdown of EXPERTISE.

NAV/CONF_BIN	Expert	Novice	Average
On-track	63.61%	70.18%	65.35%
High	58.54%	48.25%	55.81%
Low	5.06%	21.93%	9.53%
Off-track	36.39%	29.82%	34.65%
High	**28.16%**	**23.68%**	26.98%
Low	8.23%	6.14%	7.67%
Total	100.00%	100.00%	100.00%

Table 11. Participant navigation performance matrix based on EXPERTISE. The highlighted portion shows that Expert and Novice participants were in the "dangerous" quadrant a similar amount of time

Table 11 shows that Experts were actually in the "dangerous" quadrant more than the Novice pilots, yet both were fairly close. This result is surprising, and can

again be helpful for crew coordination purposes. Although a pilot may have a lot of flight hours, it does not mean that their perception is better than Novice pilots.

b. PROFICIENT (Experience with Low-Level Desert Navigation)

Analysis on the effect of PROFICIENT was examined just as EXPERTISE. This analysis looks to show if there is any correlation between pilots who have experience with low-level desert navigation and those who have very little to none. There were seven participants who were PROFICIENT and eight who were not. Figure 19 shows the average breakdown of CONF, ERROR1 and ERROR2 for each route based on PROFICIENT.

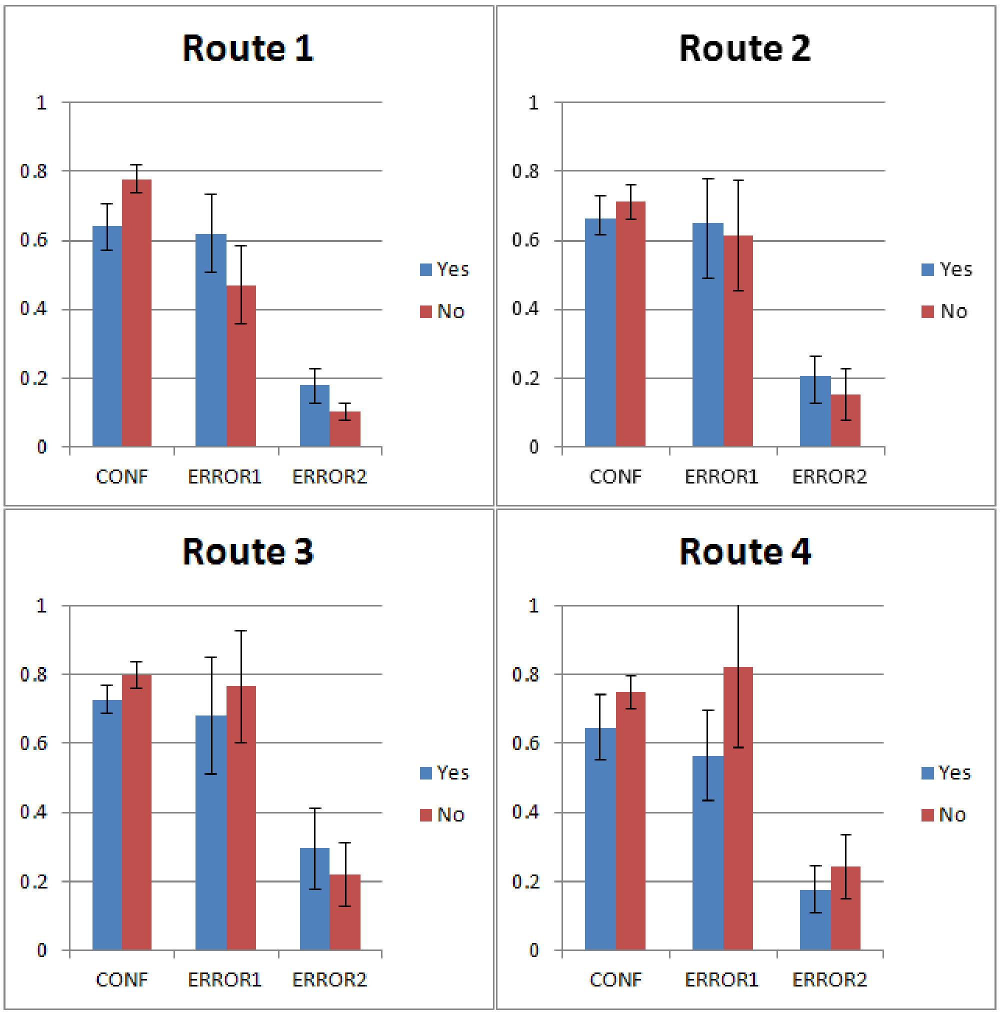

Figure 19. Column graphs of PROFICIENT and average CONF, ERROR1, and ERROR2 for each route. Error bars are based on 95% confidence level.

Figure 19 shows that there is overlap in confidence levels for all three variables for each route except for CONF on route 1. This shows that PROFICIENT has little effect on participant's experimental performance. To further look into the effect of PROFICIENT Student t tests were completed and shown in Table 12.

		Route			
		1	2	3	4
CONF	t_7	-1.611	-0.772	-0.808	-1.134
	p-value	0.146	0.462	0.442	0.289
ERROR1	t_7	1.785	0.577	-0.985	-1.106
	p-value	0.0976†	0.574	0.344	0.292
ERROR2	t_7	2.675	1.180	0.637	-0.674
	p-value	0.0191*	0.261	0.536	0.513

† p<.10, * p < .05, ** p < .01, *** p < .001

Table 12. Student t-test for the correlation between PROFICIENT for CONF, ERROR1, and ERROR2 for each route.

Table 12 shows that there is little statistically significant differences between PROFICIENT pilots. Although not significant, it is interesting to note that for every route, CONF was lower for pilots who were PROFICIENT. This may at first seem a little counterintuitive, because one would think that they would be more confident with their abilities. However, they could have been less confident because they know how easy it is to misperceive terrain in the desert environment. The only statistically significant difference is ERROR2 for route 1. This could show that PROFICIENT pilots had less bias to the intended route of flight for route 1. Because this is the only significant result, and that ERROR2 is not significant for the other routes (ERROR2 is actually higher for PROFICIENT pilots in route 4), PROFICIENT no effect on this experiment.

PROFICIENT was then checked to see if it had a correlation effect on the "dangerous" quadrant of the performance matrix. Table 13 shows the performance matrix breakdown based on PROFICIENT.

	PROFICIENT		
NAV/ CONF_BIN	**Yes**	**No**	**Total**
On-track	65.83%	64.94%	65.35%
High	49.25%	61.47%	55.81%
Low	16.58%	3.46%	9.53%
Off-track	34.17%	35.06%	34.65%
High	**22.61%**	**30.74%**	26.98%
Low	11.56%	4.33%	7.67%
Total	100.00%	100.00%	100.00%

Table 13. Experimental performance matrix based on PROFICIENT

Table 13 shows that there is a significant difference between the PROFICIENT and the "dangerous" quadrant of the performance matrix. This again goes back to the findings that the PROFICIENT pilots were on average less confident than non-PROFICIENT pilots. Both PROFICIENT and non-PROFICIENT were off track about the same amount of time, but the PROFICIENT pilots were able to adjust their confidence better than non-PROFICIENT. Although PROFICIENT pilots were in the "dangerous" category less often, 22.61% compared to 30.74%, they were also less confident when they were on course compared to non-PROFICIENT. Non-PROFICIENT pilots had correct perception (NAV On-track and High CONF, NAV Off-track and Low CONF) 65.8% of the time while PROFICIENT pilots had correct perception only 60% of the time. This shows that PROFICIENT pilots were less confident during the routes, but enough to be statistically significant. This led to the fact that differences in the performance matrix exist.

E. LEARNING EFFECTS OF EXPERIMENTS

1. Learning Effect (Past Experiment Participants vs. First Timers)

This experiment had three participants who had previously conducted a similar experiment. These participants could have a learning effect because they had already seen a similar OTW view and controlled a simulated aircraft. These participants had seen Sullivan's (2010) route, so they could have an advantage over other participants during the two autonavigation routes that were based off Sullivan's (2010) route. Analysis was

conducted to see if these three participants skewed the data. Figure 20 shows the average breakdown of CONF, ERROR1, and ERROR2 based off of PAST_EXP.

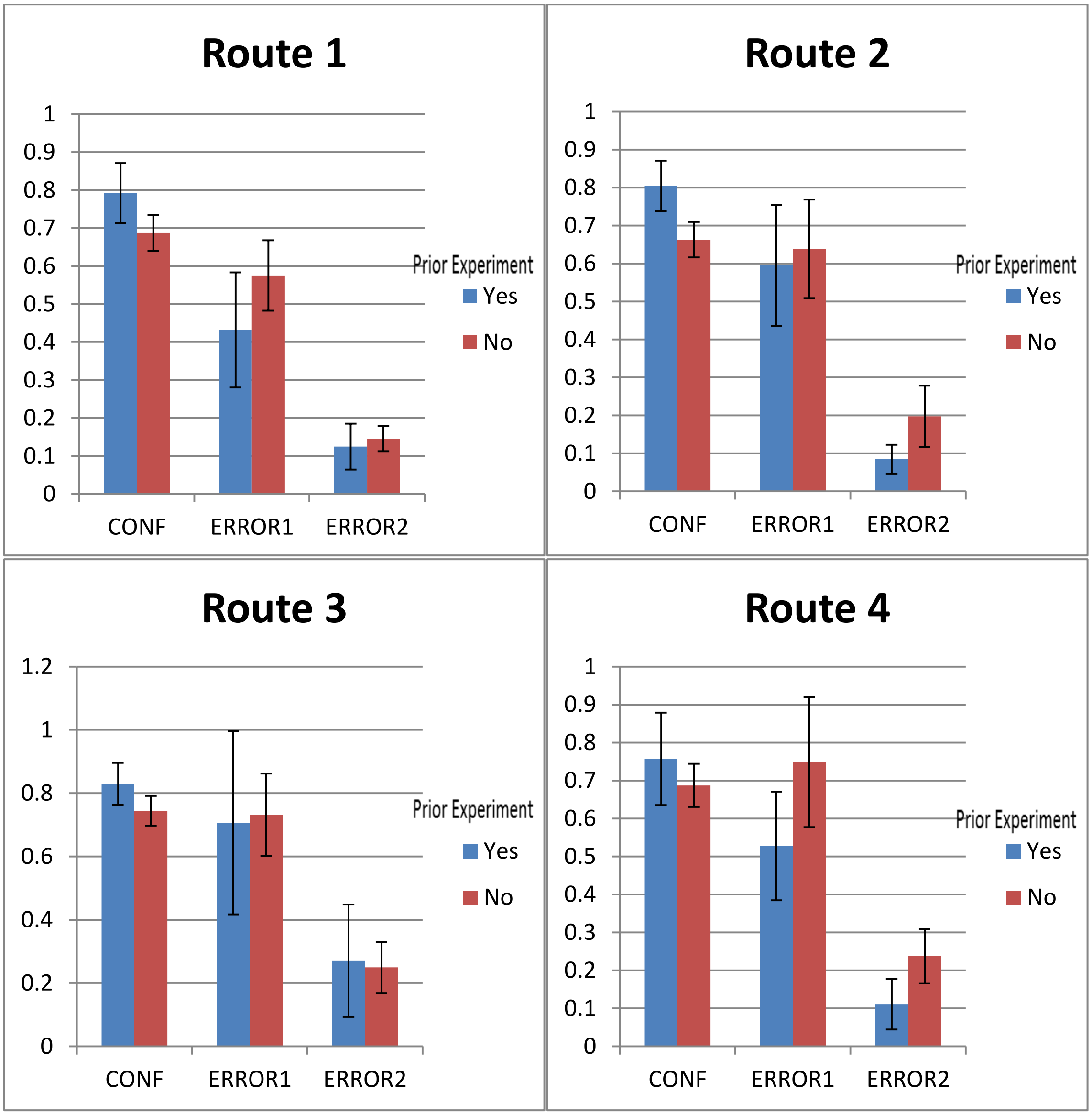

Figure 20. Comparative column graphs of CONF, ERROR1, and ERROR2 based on PAST_EXP for each route. Error bars are for 95% confidence level.

Figure 20 shows that the 95% confidence level bars overlap for each variable and each route except for CONF and ERROR2 on route 2. This shows that there does not seem to be a significant learning effect for participants who participated in a prior

experiment. Figure 20 does show that those who have completed prior experiments had higher CONF and lower ERROR1. To see if these differences are significant, Student t tests were conducted and shown in Table 14.

		Route			
		1	2	3	4
CONF	t_2	1.292	2.289	0.922	0.902
	p-value	0.266	0.0620†	0.408	0.402
ERROR1	t_2	-1.476	-0.486	-0.153	-1.519
	p-value	0.236	0.652	0.887	0.155
ERROR2	t_2	-0.592	-3.026	0.135	-2.092
	p-value	0.596	0.0105*	0.901	0.0566†

† $p<.10$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 14. Student t tests comparing PAST_EXP for CONF, ERROR1, and ERROR2 on each route.

Table 14 shows that there is little statistically significant differences in the data except for ERROR2 for route 2. ERROR2 significance shows that the participants with PAST_EXP actually had more bias in their navigation. Otherwise, PAST_EXP had no effect on hypothesis analysis. PAST_EXP was analyzed in the performance matrix in Table 15.

	PAST_EXP		
NAV/ CONF_BIN	**Yes**	**No**	**Total**
On-track	73.56%	63.27%	65.35%
High	66.67%	53.06%	55.81%
Low	6.90%	10.20%	9.53%
Off-track	26.44%	36.73%	34.65%
High	**24.14%**	**27.70%**	26.98%
Low	2.30%	9.04%	7.67%
Total	100.00%	100.00%	100.00%

Table 15. Experimental performance matrix based on PAST_EXP. The Highlighted portion suggests that participants who conducted in a past experiment were in the "dangerous" quadrant a similar amount of time as those who did not.

As Table 15 shows, PAST_EXP participants spent a higher percentage of time On-track, but they had about the same percentage in the "dangerous" quadrant of the

matrix. This means that when they were Off-track they still believed they were tracking on-course. This shows that PAST_EXP participants did not skew the analysis of pilots in the “dangerous” quadrant, meaning that PAST_EXP does not have a large effect on the data. There are some minor differences, but they do not detract from the conclusions of the study.

2. Between Scenario Differences

This section investigates if there is a learning effect during the course of the experiment. Paired t-tests were solved for CONF, ERROR1, and ERROR2 for each of the routes, and shown in matrix format in Tables 16 through 18.

CONF $t_{14,\ 0.05}$

Routes	1	2	3	4
1	---			
2	2.603 p-value 0.0219*	---		
3	-2.443 p-value 0.0284*	-3.674 p-value 0.00281**	---	
4	1.012	-1.168	3.404 p-value 0.00428**	---

† p<.10, * p < .05, ** p < .01, *** p < .001

Table 16. T-test matrix on the learning effect of CONF and route

Table 16 shows that there was statistically significantly different CONF between some of the routes. The cart shows that route 1 and route 4 had similar CONF data while routes 2 and 3 had similar data. The difference in CONF is not too surprising, because the routes were set up to have varying difficulties. Route 1 was supposed to be harder than route 2, causing the CONF to be lower in route 2 than route 1. With a harder route, there are more chances for the participant to get off-track, thereby reducing their CONF level. Route 3 and 4 were set up to be similar, but there is a large difference in the data. The participants’ realization at the end of route 3 that the autopilot did not follow the

intended route may have caused the difference. This caused the participant to be less confident in the location of route 4. The data shows that there was not a trending effect of increased or reduced confidence throughout the experiment.

ERROR1 $t_{14,\ 0.05}$

Routes	1	2	3	4
1	---			
2	-1.718	---		
3	-2.622 p-value 0.0201*	-1.629	---	
4	-1.620	-0.408	0.199	---

† p<.10, * p < .05, ** p < .01, *** p < .001

Table 17. Correlation matrix on the learning effect of ERROR1 and route

Table 17 shows the surprising result of the limited effect that the routes had on ERROR1. Participants had similar perception errors on all of the routes.

ERROR2 $t_{14,\ 0.05}$

Routes	1	2	3	4
1	1			
2	-1.494	1		
3	-1.887 p-value 0.0800†	-1.341	1	
4	-1.544	-0.722	0.677	1

† p<.10, * p < .05, ** p < .01, *** p < .001

Table 18. Correlation matrix on the learning effect of ERROR2 and route

Table 18 shows limited statistical significance that the route had on ERROR2. The participants had a similar bias to the intended route for every route.

F. POWER ANALYSIS

The power of a statistical test is the probability that the test will reject the null hypothesis when the null hypothesis is actually false, or commonly, the probability of not committing a Type II error. The power analysis will conclude if the experimental sample size was large enough to give significant results.

Power analysis was conducted for the significant correlation coefficients for routes 1 and 4 of hypothesis 2. This analysis was for a one-sided less than test with sample size of 15 and an alpha of 0.05. ρ values of -0.65 and -0.596 correlate to a power of 0.858 and 0.776 respectfully. The test will successfully reject the null hypothesis when the null hypothesis is actually false 85.8% for route 1 and 77.6% for route 4. This power is high considering the small sample size of the experiment, meaning that pilot bias toward the intended route is likely (Cohen, 1988).

G. POST TASK QUESTIONNAIRE RESULTS

At the completion of the navigation and debriefing portion of the experiment, the participants were given a Post Task Questionnaire (Appendix). This questionnaire was written to answer two questions. The first was to obtain navigation techniques that the more successful pilots used, while the later was an attempt to normalize CONF levels. In the attempt to normalize the CONF levels, some interesting outcomes arose. The first being that only one participant felt that pilots were not over reliant on navigation equipment like GPS, with six neutral responses and eight positive. The second result of the questionnaire is that 12 of the 15 participants thought that it was easy to misinterpret terrain during overland navigation, with the other three responses being neutral. The last questionnaire output was the most interesting. Only two participants (13.3%) believe that they are overconfident in their navigation skills. This is surprising considering the percentage of time the participants were in the “dangerous” quadrant of flight. When the participant was Off-track, they had a high confidence, or wrong perception. This suggests that pilots are misperceiving their overconfidence during navigation.

H. SUMMARY

The results of the experiment showed that participants spent 27% of the time in the “dangerous” quadrant of the performance matrix, second only to On-track and High CONF. It also showed that participants spent a higher percentage of time in the “dangerous” quadrant for the autonavigation routes. The next data result was that there was no correlation between EEROR1 and confidence, yet there was correlation between ERROR2 and confidence. This means that participant’s confidence did not decrease when perception error increased, but confidence did decrease when the perceived distance from the route increased. Analysis was then conducted to see in CONF and ERROR1 changed with navigation duration. CONF decreased and ERROR1 increased the longer into the route the participant was. Lastly exploratory analysis was conducted to see if there was an experience or learning effect on the experiment. Data showed that EXPERTISE and PROFICIENT had little effect on the experiment. Analysis also showed that participants who completed similar experiments did not skew the data. Lastly analysis showed that there was some statistically significant differences in CONF between each route, but these differences could be explained with the different route complexities, but ERROR1 and ERROR2 had little difference between routes.

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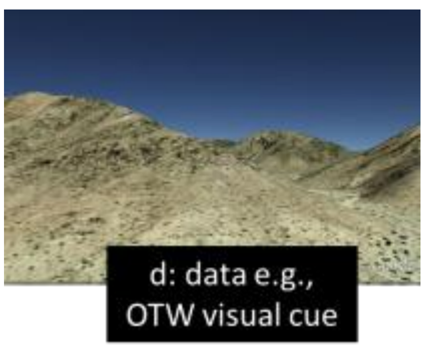
IV. MODELING MISPERCEPTION IN BAYESIAN FRAMEWORK

This section provides the insights gained by modeling pilot misperception in a Bayesian framework. The model classifies misperception categories, and determines when pilots are likely to fall into these categories during overland navigation.

A. BAYESIAN MODELING OF MISPERCEPTION

Table 2 is an overview of the Bayesian misperception modeling for overland navigation from Yang et al. (2011). Overland navigation requires the pilot to estimate their location over the ground given the outside terrain features presented to them. To model this, two variables are defined and shown in Figure 21.



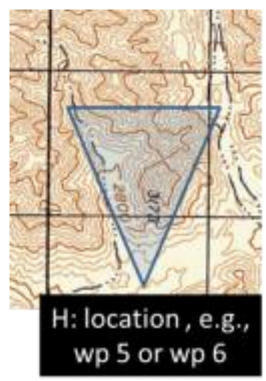


Figure 21. Bayesian misperception model variables. *d* is data, which includes the OTW visual cues or terrain features. *H* is the location of the aircraft over the ground.

In this model, pilots are required to estimate *p(H|d)*, where *H* is the location or orientation of the aircraft, and *d* is the data or visual cue that the pilot receives OTW. Then, *p(H|d)* the probability of a pilot's current location being at *H* after seeing a visual *d* cue can be obtained by applying Bayes' rule:

$$p(H \mid d) = \frac{p(d \mid H) * p(H)}{p(d \mid H) * p(H) + p(d \mid \sim H) * p(\sim H)} \tag{1}$$

In equation (1), $p(H)$ is the prior probability, i.e., the pilot's belief probability that they are at location H before seeing scene d. $p(d|H)$ is the conditional probability that the pilot sees d from OTW when they are at location H, while $p(d|{\sim}H)$ is the conditional probability that the pilot sees d OTW when they are in a different location, (${\sim}H$). Therefore, $p({\sim}H)$ is equal to $1- p(H)$, or the probability the pilot is not at location H.

The first misperception type is when pilots take the map data and try to fit it into what they see OTW. This suggests that they are estimating $p(H|d)$ as $p(d|H)$,confusing inference with evidence. This misperception is prevalent when the pilot believes they are on-track, and scene d is likely, or $p(d|H) \approx 1$. The pilot will then estimates $p(H|d)$ *is* $p(d|H) \approx 1$, which incorrectly overestimates the probability. This approximation is incorrect and leads the pilot to view OTW scenes in a biased manner and to be overconfident.

A second type of misperception occurs when pilots assume that the terrain that they see cannot look like terrain in a similar area. They are assuming mutually exclusive events from evidence, or $p(d|{\sim}H) = 1 - p(d|H)$. This assumption is incorrect because some areas can have very similar terrain to other areas causing a similar visual cue (e.g., a hill or valley), that can be observed at different locations $p(d|H) = p(d|{\sim}H)$. Pilots acting under this misperception show a bias to where they perceive they are on the map and do not consider that the location they see out the map could be another spot on the map, or ${\sim}H$. This misperception is shown in the equation (2),

$$p(H|d) = \frac{p(d|H)*p(H)}{p(d|H)*p(H)+(1-p(d|H))*p(\sim H)} \tag{2}$$

The third misperception type is when pilots disregard visual cues that do not fit into their current belief. Pilots will also only use visual cues that are compatible with their current perceived location. This means that pilots estimate $p(H|d)$ to equal the prior probability $p(H)$. Not only are pilots disregarding visual cues, they are only accepting visual cues that support their perception. This misperception type can be attributed to Inattentional Blindness (Simons & Chabris, 1999).

B. NAVIGATION PERFORMANCE AND CONFIDENCE COMPARISON

In this section, an illustrative case study is made of two subjects' navigation performances. Route 3 was chosen for this comparison because the autonavigation allows for the pause points to be in the exact same location, and the participants have the same OTW view. This comparison focuses on pause points 3 through 6, the valley that nine of the 12 participants missed in Sullivan (2010). Participant 3 was chosen because they showed correct perception during the navigation, while Participant 5 had incorrect perception. Both of these participants were helicopter pilots with over 1,000 total flight hours and neither had participated in a previous experiment. Figure 22 shows Participant 3 and 5's navigation performance for route 3.

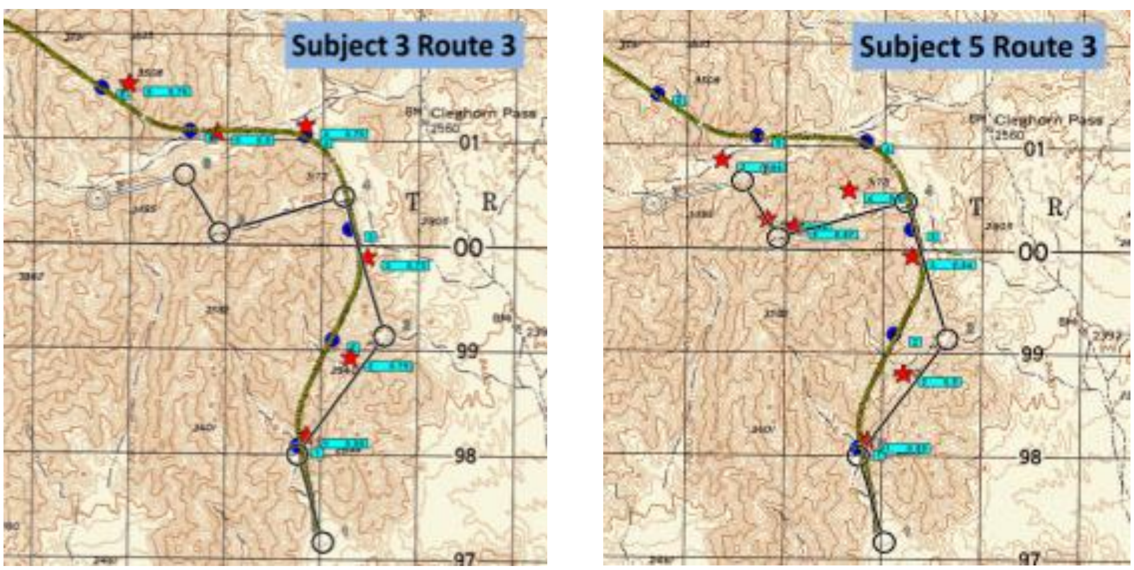


Figure 22. Route 3 data for Participants 3 and 5. Black line is the intended route of flight, yellow line is the auto-pilot flight path, red star is perceived aircraft location with pause point number and confidence label, and blue circles are actual aircraft location with pause point label. Notice Participant 3 has correct perception while Participant 5 believes aircraft followed intended route.

Figure 22 shows the misperception of Participant 5 versus Participant 3. Participant 3 was able to realize that the auto-pilot did not follow the intended route, and the perceived and actual location was close. Conversely, Participant 5 did not realize that

the aircraft deviated from the intend course. This caused Participant 5 to still perceive the aircraft's location on the intended route, as can be seen with the red stars close to the black line. Figure 23 and Table 19 gives the breakdown of CONF, ERROR1, and ERROR2 for Participants 3 and 5.

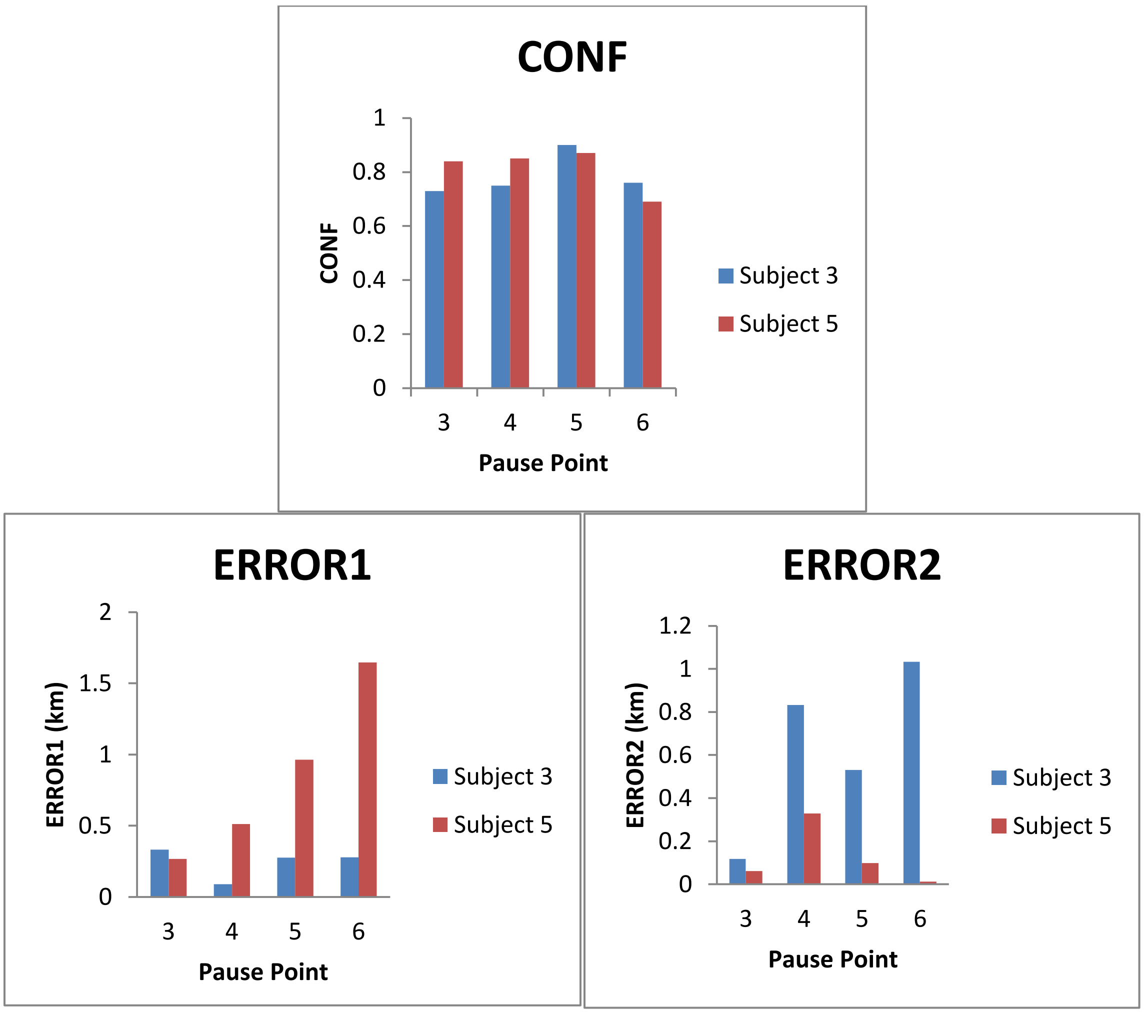


Figure 23. Comparative column graphs that show the differences in CONF, ERROR1, and ERROR2 for Participants 3 and 5. Notice the similar CONF but large differences in ERROR1 and ERROR2.

Route 3 Subject 3				**Route 3 Subject 5**			
Pause Point	**CONF**	**ERROR 1 (km)**	**ERROR 2 (km)**	**Pause Point**	**CONF**	**ERROR 1 (km)**	**ERROR 2 (km)**
3	0.73	0.3333	0.1171	3	0.84	0.2669	0.0606
4	0.75	0.0890	0.8327	4	0.85	0.5123	0.3284
5	0.9	0.2764	0.5304	5	0.87	0.9627	0.0979

6	0.76	0.2775	1.0330	6	0.69	1.6466	0.0121

Table 19. CONF, ERROR1, and ERROR2 for subjects 3 and 5 during route 3. Notice the lower CONF and ERROR1 and higher ERROR2 for subject 3.

Table 19 shows the difference of CONF, ERROR1 and ERROR2 between Participants 3 and 5. Participant 3 had lower CONF for two of the four pause points than Participant 5 even though they had better perception, or lower ERROR1. This outcome is explained by our previous findings under hypothesis 1, that there is no correlation between CONF and ERROR1. Participant 3 also has a much larger ERROR2 than Participant 5. A larger ERROR2 is better for this area of the route because the auto-pilot is not following the intended route. By having a relatively low ERROR2, Participant 5 shows a bias towards the intended route. This bias will be critical in determining the misperception types experienced by the participant.

The next step in modeling the misperception of participants is to look at the route and find key terrain features that participants can use to determine their location. Figure 24 shows key terrain of route 3.

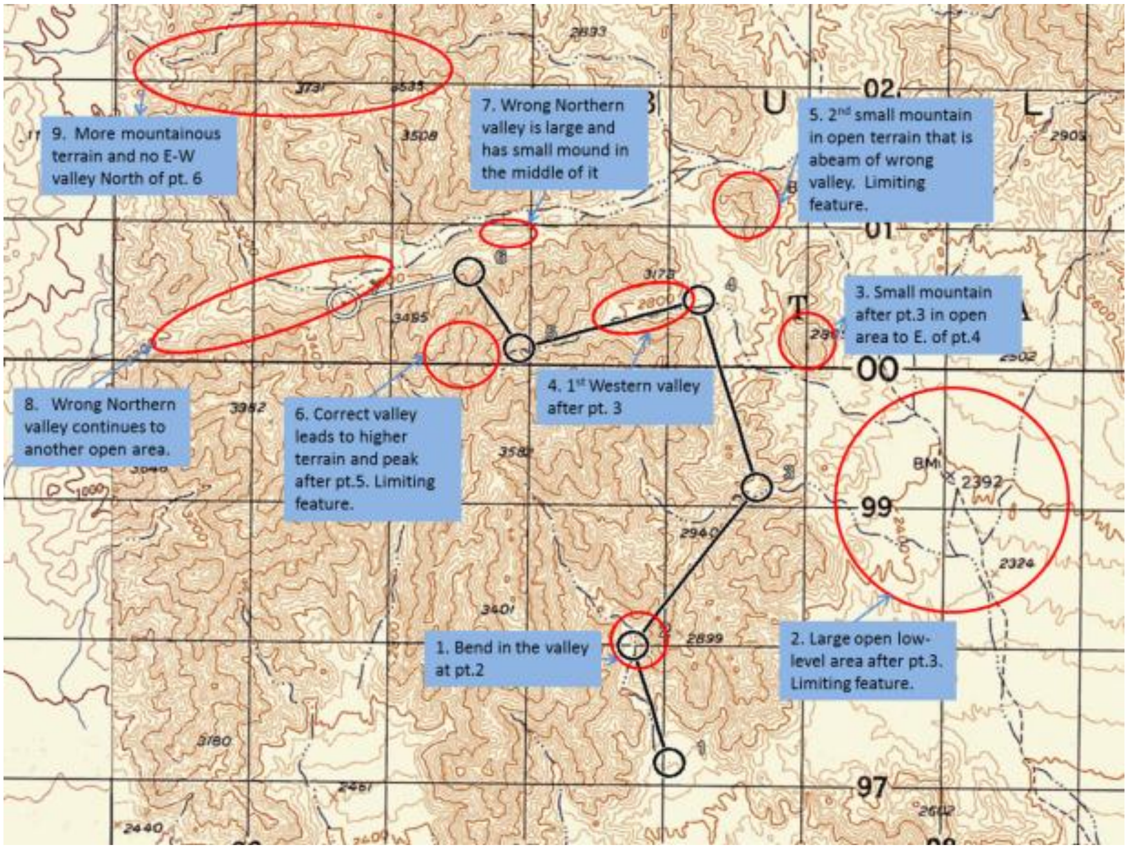


Figure 24. Key terrain features of route 3. These terrain features should have been used by the participants to determine their position.

The key terrain features in Figure 24 could be used as a guide to notify the participant that the autonavigation is not following the intended route of flight. After passing WP 3, the participant should notice two hills off the right side of the aircraft (3. and 5. on Figure 24). The participant needs to turn left into the valley at WP 4 after passing the first hill, and should have realized that they have gone too far if they pass the second hill. The valley at WP 4 is also the first valley to the left after WP 3. This valley is narrow and it has rising terrain after WP 5. The valley through which the autopilot guides the participant is wide, and has a small mound in the middle (7. on Figure 24). This valley does not have any rising terrain and continues to another large, low-level open area. Key terrain 9, on Figure 24 is a mountainous area and not the valley that one would expect to see at WP 6.

C. MISPERCEPTION SIMULATION

In this section Participant 5's route 3 navigation from WPs 3 through 7, or pause points 3 through 6, are analyzed and modeled. Starting at pause point 3, participant 5 showed correct perception, following the autonavigation of the aircraft. It is at pause point 4 where Participant 5 fell into one of the misperception types. At pause point 4, the aircraft was turning into a valley to the North of the intended route. At this pause point, the aircraft was in terrain that was similar to WP 4, turning into an East to West valley. This can be described as $p(d|H) \approx p(d|{\sim}H)$, where d = valley and H = WP 4. In order to have correct perception at this point, the participant needed to notice they flew past the opening to the valley WP 4, and not use the small mountains off the right-hand-side of the aircraft to notice that they were too far north. It is assumed that Participant 5 did not notice these terrain features, and at pause point 4, they still believed they were on-track and had scenery that resembled WP 4. Because Participant 5 was in area that could resemble WP 4, they could have overweighed their visual cue and not considered that they were in a different valley, or $\sim H$. This could have led Participant 5 to misperception type 2. Misperception type 1 could have also occurred because Participant 5 believed they were on-track and a valley should be seen at the waypoint, i.e., $p(d|H)$ is high. Figure 25 shows the differences in prior and posterior probabilities for pause point 4 for Participant 5 acting as a Bayesian agent and for misperception types 1 and 3. Figure 25 assumes that $p(d|H) = p(d|{\sim}H) = 0.9$, which is high because WP4 and pause point 4 are similar, and $p(H)$ is the CONF at pause point 3 which is 0.84.

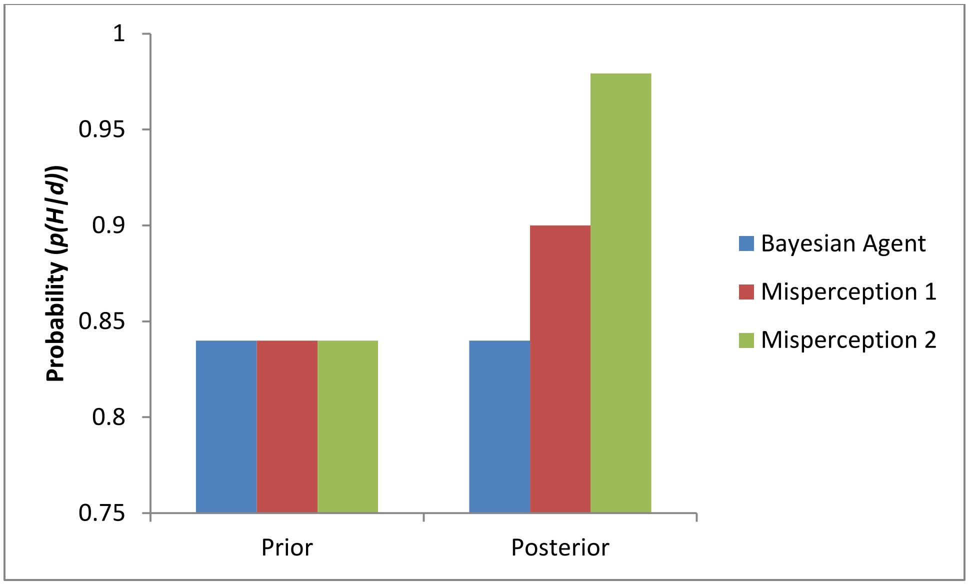


Figure 25. Column chart comparing Participant 5 during route 3 at pause point 4, assuming a high $p(d|H) = p(d|{\sim}H) = 0.9$ and $p(H)$ is the CONF at pause point 3 which is 0.84. Notice that the $p(H|d)$, or misperception 2, increases from prior to posterior for misperception types.

Figure 25 shows that the posterior probability increases for $p(H|d)$ for the misperception types 1 and 2 while the probability for the Bayesian agent stays the same. This result shows how Participant 5 could have been acting under a biased perception leading them to miscalculate their location, yet remain confident.

After the initial misperception of Participant 5 at pause point 4, they misperceived pause point 5 and 6. Both of these pause point misperceptions relate to misperception type 3. While the aircraft is transiting down the wrong valley, there are visual cues that would allow the pilot to update their position and correct their perception. The first visual cue is that the Northern valley is much larger than the correct one to the South. This incorrect valley has a noticeable small mound in the middle of it, and it remains flat while the correct valley is narrow with increasing terrain after waypoint 5. Although Participant 5's CONF did reduce from pause point 5 to 6, it was still biased to the intended route of flight. It is assumed that this reduction was mostly due to the small distance in perceived location between pause points 5 and 6. Misperception 3 means that the participant is only seeing terrain that helps their already biased view that they are on-course.

D. SUMMARY

This chapter provided insights gained by modeling pilot perception and misperception during overland navigation in a Bayesian framework. Pilots can correctly update their position in an unbiased manner using Bayesian updating when acting as a true Bayesian agent, and they can fall into one of the misperception types when not acting as a Bayesian agent.

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V. CONCLUSION AND DISCUSSION

A. RESEARCH LIMITATIONS AND ASSUMPTIONS

The largest limitations affecting this study was the limited number of available participants, and potential bias of aviators who are students/ staff at the Naval Postgraduate School, which could narrow the range of flight experience in the sample. To partially overcome this limitation, participants were recruited from students and faculty of the Naval Postgraduate School with various aviation communities and services, and had a wide range of experience levels. Another limitation was the use of a simulated environment and not actual aircraft. However, this drawback was minimized by using realistic outside and inside cockpit views. It has also been shown that navigation in a virtual environment correlates to real world navigation (Hahn, 2005). Due to safety concerns, this study could not be conducted at this altitude in a real aircraft over similar terrain.

Human confidence is complicated. People have different perspectives and different baselines of confidence. Because of this variability between individuals, correlation of confidence is based off a specific route at a specific time. Self-reported confidence was assumed to be linear on a 0 to 100% scale.

Another limitation of the experiment was the relatively small field of view and no depth perception of the OTW display. In the real world, pilots have the ability to scan left and right, but in this experiment, they were limited to looking directly in front of the aircraft with a 65-degree field of view. This made the navigational task more challenging because precise dead reckoning requires the pilot to get the intersection of at least two bearing lines off known terrain features. With only the forward view, the baring lines are at acute angles making it hard to get an exact pinpoint of location. To compensate for this, the participants were informed that the experiment was not seeking the exact location, but rather the general area. In addition, the challenging navigational task increased the workload and stress that can be compared to real navigation. Also, small

field of views and no depth perception are experienced in actual operating conditions when using night vision goggles with 40-degree field of view limitations.

Developing routes for the experiment is a difficult task because the subjects have varied navigational and flight experiences. The experiment should be set up in a way that each participant has a reasonable expectation of both success and failure. Because of this fact, four routes including two autonavigation routes had to be developed in order span all experience levels. Another limitation of the experiment was the required pause points. The pause points required stops in navigation that could have an adverse effect on the experiment. To reduce the effect of pausing the navigation task, participants were told that marking their perceived location and confidence should take five seconds and not more than ten. This time limitation helped reduce the irritation of pausing the navigation, and also did not allow the participant extra time to study the map and OTW display to enhance their navigation performance. Participants were also polled after the navigation task, and none believed that the pause points had a negative effect on their navigational task. The pause points also caused difficulty in participants who wanted to use timing to supplement their visual navigation. The digital clock they were provided on their instrument cluster was constantly running, and it did not stop when the navigation was paused. Again, this forced the participants to focus on their visual navigation, and not dead reckoning. Pausing is another aspect of this study that could not be performed in an aircraft.

The final limitation of the experiment dealt with the map display. The participants were not allowed to use the paper map that they used for their map study. This did take away from some of the realism of the simulation. Real world navigation involves multiple techniques including GPS navigation, visual navigation, and instrument navigation focusing on heading and timing. For the purpose of this experiment, we focused on the visual navigation. The map display causes the participant to focus on this area, with minor use of heading and timing. Another simulation question arose about how to deal with the orientation of the map. During real world map navigation the PNAC usually orients the map in the direction of travel. This eases the cognitive tasking of orienting outside objects to the helicopter. Having to deal with manually orienting the

map and flying, increased the workload inside of the simulated cockpit. For this experiment, allowing the participants to change the heading of the map caused an additional distraction and reduced the amount of normalization for the experiment. Having the map automatically adjust to the helicopter heading demonstrated to be disorienting to some participants (Sullivan 2010). Because they were not the ones moving the map, it was hard for them to regain their location after moving from the OTW to the map display.

B. CONCLUSIONS

This experiment showed that pilots have biased perception when they are executing low level navigation routes. The participants in this study were in the "dangerous" quadrant of the navigation performance matrix (Off-track and High CONF) 27% of the time, which was second only to On-track and High CONF. Of the time that the participants were Off-track, they had a corresponding High CONF 77.9% of the time. This shows that the participants overestimated their navigation performance, yet in a post task questionnaire only two of the 15 participants believed they were overconfident in their navigation abilities. This again shows that there is lack of correlation between performance and confidence. Just as participants were biased towards overestimates of personal ability in Stone's (1993) research, the participants in my experiment overestimated their navigation performance in the complex cognitive task of navigation without their knowledge. That participants are overestimating their abilities without their recognition can be the cause of mishaps and mission failures, just as unrecognized spatial disorientation is the most dangerous disorientation and is attributed to the most disorientation mishaps.

The next important result from the study is that there is no correlation between navigation performance and confidence, yet there is correlation between the distance between perceived location and intended route versus confidence. This suggests that the further a pilot is away from their perceived location; their corresponding confidence does not decrease. The correlation between perceived location and intended route versus confidence suggests that the pilots would decrease their confidence the further from their

perceived location was from the intended route. This shows that the pilots could have a bias towards the intended route of flight.

Data from this experiment also showed that participant's total flight hours, experience with low-level desert navigation, and whether the participant participated in similar experiment had little effect on the above results. This result suggests that navigation misperception is a symptom of traits ingrained in human nature. If this is the fact, additional training and technologies will have to be developed in order to override this biased thinking.

The final conclusion is that the output from this experiment could allow low-level helicopter navigation to be modeled in a Bayesian framework in order to understand pilot misperception. The experiment showed that when a participant is not acting as a Bayesian agent, they can fall into one of the three misperception types: 1. Pilots take the map data and try to fit it into what they see OTW. 2. Pilots assume that the terrain that they see cannot look like terrain in a similar area. 3. Pilots disregard visual cues that do not fit into their current belief.

C. IMPLEMENTATION

Direct implementation of the results from this experiment to new procedures and technologies is difficult because it involves personal confidence. The most important result from the experiment is that there needs to be training on this subject to give pilots the ability to recognize that confidence does not correspond to correctness during navigation. A single simulator event, possibly conducted in conjunction could be implemented into the Advanced Helicopter Flight Training at NAS Whiting Field and possibly to the Aviation Pre-Flight Indoctrination (API) at NAS Pensacola, along with the corresponding Army and Air Force helicopter training schools, based on the finding of this experiment. Results from this experiment could also be added to aviation physiology and safety center documents.

Results from this experiment also suggest that helicopter navigation equipment is important for correct navigation performance. Any improvements in navigation equipment technology, that would reduce the reliance on visual navigation, would relate

to less mishaps and mission failures. Current fleet navigation equipment requires large amount of pilot input. Reducing the pilot input requirements can allow the PNAC to better execute other duties in the cockpit.

The last implementation of the results from this experiment involves changing the Go-No-GO requirements for overland navigation. Currently GPS is considered a supplemental navigation devise, and it is not required to execute overland low-level navigation. This experiment shows that is not uncommon for pilots to misperceive their location just using visual navigation, and this misperception could be alleviated with navigational equipment like GPS.

D. FUTURE WORK

To enhance the results of this experiment a larger sample size spanning different experience and communities could be used. The larger sample size would allow for a better experience grouping of participants (expert, intermediate, and novice). Being able to effectively group the participants could provide insights into “overconfident” or “dangerous” population. This could pinpoint where dedicated time and technology needs to be spent.

The experiment could also be conducted under realistic operation environments. These environments could be nighttime, emergencies, and different weather conditions. Again this would enhance the data for real world operations.

The last future work is to combine model data to pilots as they are flying in a training simulator. This would be a real-time interactive training system that would notify pilots about the dangers and occurrence of misperception. This training would help reduce the amount of misperception during operational navigation.

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APPENDIX

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation Welcome Script

Date:

Subject ID:

Scheduled Arrival Time:
Actual Arrival Time:
Hello and welcome. Thank you for participating. We hope that your participation will ultimately lead to improvements in our understanding of pilot misperception during overland navigation.
Today we'll be asking you to complete a four short navigation exercise using a pc-based simulation. Before and after the navigation, we'll ask you to fill out some short questionnaires related to your background and experience. During the navigation we will be pausing the simulation and asking you to pinpoint where on the map you are, and at what confidence (100 very confident….0 very lost).
We hope to take less than 45 minutes. We ask for uninterrupted participation. During the simulation exercise and when near equipment, please observe no food/drink restrictions. If you need to use a restroom they are located across the breezeway, through the double doors and to the left. Bottled water is available in the fridge by the door.
Are you ready to go on?
The next step is to make sure you understand any risks, the voluntary nature of participation and our efforts to protect your privacy with the consent form.

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation
Experiment check list

Subject ID:

- ☐ E-mail confirming date and time
- ☐ Notify lab participants of data collection time
- ☐ Validate equipment hardware and software
    - o Screen brightness and contrast settings
    - o Lab lighting conditions
- ☐ "Experiment in Progress" signs
- ☐ Bottled water in fridge.
- ☐ Introductory Script
- ☐ Informed Consent
- ☐ Background questionnaire
- ☐ Map set up
- ☐ Route brief
- ☐ Trial period instructions
- ☐ Audio recording equipment (storage media, files naming and backup scheme)
- ☐ Navigation exercise
- ☐ Save and backup data; folder name: subject ID and date
- ☐ Post exercise questionnaires
- ☐ Wrap up and thank you, contact information

Date:

Naval Postgraduate School
Consent to Participate in Research

Introduction. You are invited to participate in a research study entitled "Pilot Confidence during Helicopter Overland Navigation." The purpose of the research is to give an understanding why pilots track off course during navigation.

Procedures. This study entails navigation through a simulated environment. You will initially fill out a questionnaire on your experience level. You will then be given a practice route to gain familiarity with the system. Following the practice, you will fly four navigation routes all preceded by a map study. The second two routes will be flown on autopilot, where the autopilot route may or may not be on course. During the navigation you will be asked to pinpoint your location on a map, and the confidence of that location. You will also be given questionnaires before and after each navigation route. The experiment is expected to take no longer than 45 minutes. We are expecting you to be one out the 20–30 participants in this study. Audio will be recorded so that we can better replay the simulation and analyze the results. The recording will be securely kept by the primary investigator, will be kept confidential, will be reported in an anonymous fashion, and will be erased after the required holding time.

Location. The interview/survey/experiment will take place in the MOVES Institute, Watkins Building, Rm #212B.

Cost. There is no cost to participate in this research study.

Voluntary Nature of the Study. Your participation in this study is strictly voluntary. If you choose to participate you can change your mind at any time and withdraw from the study. You will not be penalized in any way or lose any benefits to which you would otherwise be entitled if you choose not to participate in this study or to withdraw.

Potential Risks and Discomforts. The potential risks of participating in this study are minimal. There is a risk of potential data mismanagement.

Anticipated Benefits. Anticipated benefits from this study are to understand the reason for pilot visual perception during overland navigation; increasing the ability to train future pilot and giving recognition and better practices to current pilots. You may not directly benefit from your participation in this research. The alternative to participating in the research is to not participate in the research.

Compensation for Participation. No tangible compensation will be given.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. All references to data collected will be made anonymous. Your name will be encoded as a participant number. Only principle investigators will have access to this key that translates to an identification number to your name.

If you consent to be identified by name in this study, any reference to or quote by you will be published in the final research finding only after your review and approval. If you do not agree, then you will be identified broadly by discipline and/or rank, (for example, “fire chief”).

☐ I consent to be identified by name in this research study.

☐ I do not consent to be identified by name in this research study.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, Dr. Ji Hyun Yang, *jyan1@nps.edu*. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, CAPT John Schmidt, USN, 831–656–3864, jkschmid@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

______________________________________ __________________

Participant’s Signature Date

______________________________________ __________________

Researcher’s Signature Date

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation Background Questionnaire

We are interested in learning about your navigation and flight experiences.

1. Please provide the following information:
   Age Gender

The following questions ask about your **navigation** experiences.

2. To what extent have you participated in activities other than overland navigation that may contribute to improved navigation skills? (Examples may include sport orienteering, land navigation exercises, boy/girl scouts etc.)?

○	○	○	○	○
No Related Experience	Very Limited Related Experience	Limited Related Experience	Somewhat Significant Experience	Significant Related Experience

3. At your peak of currency, how would you rate your navigation skills in a low-level (below 200’ AGL) overland environment?

○	○	○	○	○
Poor	Fair	Average	Good	Excellent

4. If tasked today, how would you rate your navigation skills in a low-level (below 200’ AGL) overland environment?

○	○	○	○	○
Poor	Fair	Average	Good	Excellent

5. How much experience do you have with low level navigation in mountainous desert terrain?

○	○	○	○	○
None	Very Little	Somewhat	Considerable	Extensive

6. How much low level navigation experience do you have in the 29 Palms area?

○	○	○	○	○
None	Very Little	Somewhat	Considerable	Extensive

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation Background Questionnaire

The following questions ask about your **flight** experiences.

1. Please provide the following information:

   Total flight hours:

   Overland hours:

   Branch of Service:

   Community:

   Years of aviation experience:

2. How many months has it been since your last flight?

3. How many months has it been since your last overland navigation flight?

4. If applicable, how many months has it been since your last search and rescue mission?

5. Describe your operational flying experience:

6. Have you participated in either of the prior navigation studies?

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation
Post Task Questionnaire

Date:

Subject ID:

Route 1:

If you believed that you did not hit every waypoint:

What was the reason?

Did you feel you misperceived some of the terrain features?

What techniques could you have used in order to not miss waypoints next time?

Date:

Subject ID:

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation
Post Task Questionnaire

Route 2:
If you believed that you did not hit every waypoint:
What was the reason?

Did you feel you misperceived some of the terrain features?

What techniques could you have used in order to not miss waypoints next time?

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation
Post Task Questionnaire

Route 3:

If you believed that you misinterpreted your position:

What was the reason?

Did you feel you misperceived some of the terrain features?

What techniques could you have used in order to gain better confidence of position next time?

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation
Post Task Questionnaire

Route 4:

If you believed that you misinterpreted your position:

What was the reason?

Did you feel you misperceived some of the terrain features?

What techniques could you have used in order to gain better confidence of position next time?

Pilot Misperception During Overland Navigation: Simulation Exercise Evaluation Post-Questionnaire

1. What do you think is the most common reason why pilots stray off course?

○	○	○	○	○
Poor Map Study	Overtasked in the Cockpit	Overconfident in Their Navigation Abilities	Lack of Notable Terrain Features	Other ________________

2. If you are in a situation where there is a chance you are not on course, do you.

○	○	○	○	○
Continue with your current track and hope you will find a major terrain feature	Return to the point where you know you were on-track and start over	Stop at your current position and try to make sense of your surrounding	Circle the area and hope to break out more notable terrain features	I never get off course

3. Do you feel that you are over-reliant on your navigation equipment like GPS?

Never	Very Little	Sometimes	Considerable	Almost Always

4. Do you feel that it is easy to misperceive terrain features when you are on low level navigation routes?

Never	Very Little	Sometimes	Considerable	Almost Always

5. Do you feel that you are overconfident in your flight and or navigation capabilities?

Never	Very Little	Sometimes	Considerable	Almost Always

6. Comments:

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